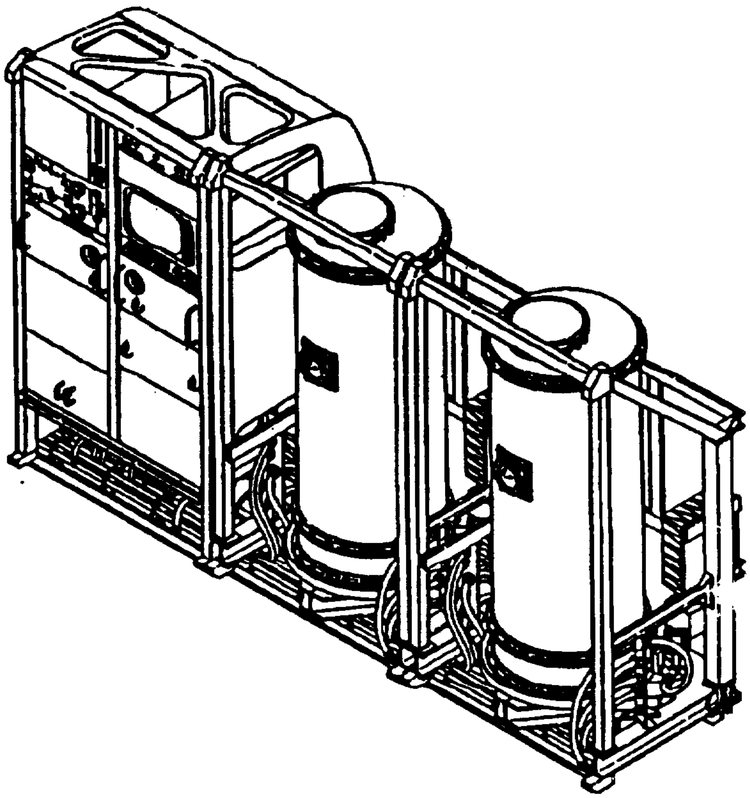
SPACE STATION FURNACE FACILITY
Environmental Analysis



DR-2
May 1992

Volume II, Appendix 3
Final Study Report (DR-8) of
Space Station Furnace Facility
Contract No. NAS8-38077

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      ABSTRACT =   A Preliminary Safety Analysis (PSA) is being acco
                  mplished as part of the Space Station Furnace Faci
                  lity (SSFF) contract. This analysis is intended to
                   support SSFF activities by analyzing concepts and
                   designs as they mature to develop essential safet
                  y requirements for inclusion in the appropriate sp
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                  n addition, the analysis identifies significant sa
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                  e proper and early resolution of safety concerns.
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SPACE STATION FURNACE FACILITY

REQUIREMENTS DEFINITION
AND
CONCEPTUAL DESIGN STUDY
FINAL REPORT
DR-8

Volume II - Technical Report
Appendix 3 Environment Analysis

Contract No. NAS8-38077
George C. Marshall Space Flight Center
Marshall Space Flight Center, Al 35812

May 1992
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OVERVIEW

This Appendix represents the summary of the safety planning activities performed under the contract. Modification 16 descoped these activities to be commensurate with the level of development of the SSFP. The Preliminary Safety Analysis was developed for the CoDR a s a Mid-term report. The information in the PSA was updated to reflect the revisions in the SSFF Conceptual Design and new hazard reports were developed. An additional task for configuration control, safety, and functional verification was added to the contract. The task reads as follows:

"A Plan for Configuration Control and Safety and Functional Verification of the integrated SSFF Flight Unit After Activities such as Experiment or Core Repair, Experiment or Core Reconfiguration, and Experiment Changeout. The plan shall consider use of prototype and GCEL units as well as the flight unit with instrumented samples. The plan shall address whether equipment such as thermal probes (for calibration), furnace borescopes, and mini-gloveboxes should be provided by the SSFF Project for the safety and functional verification activities."

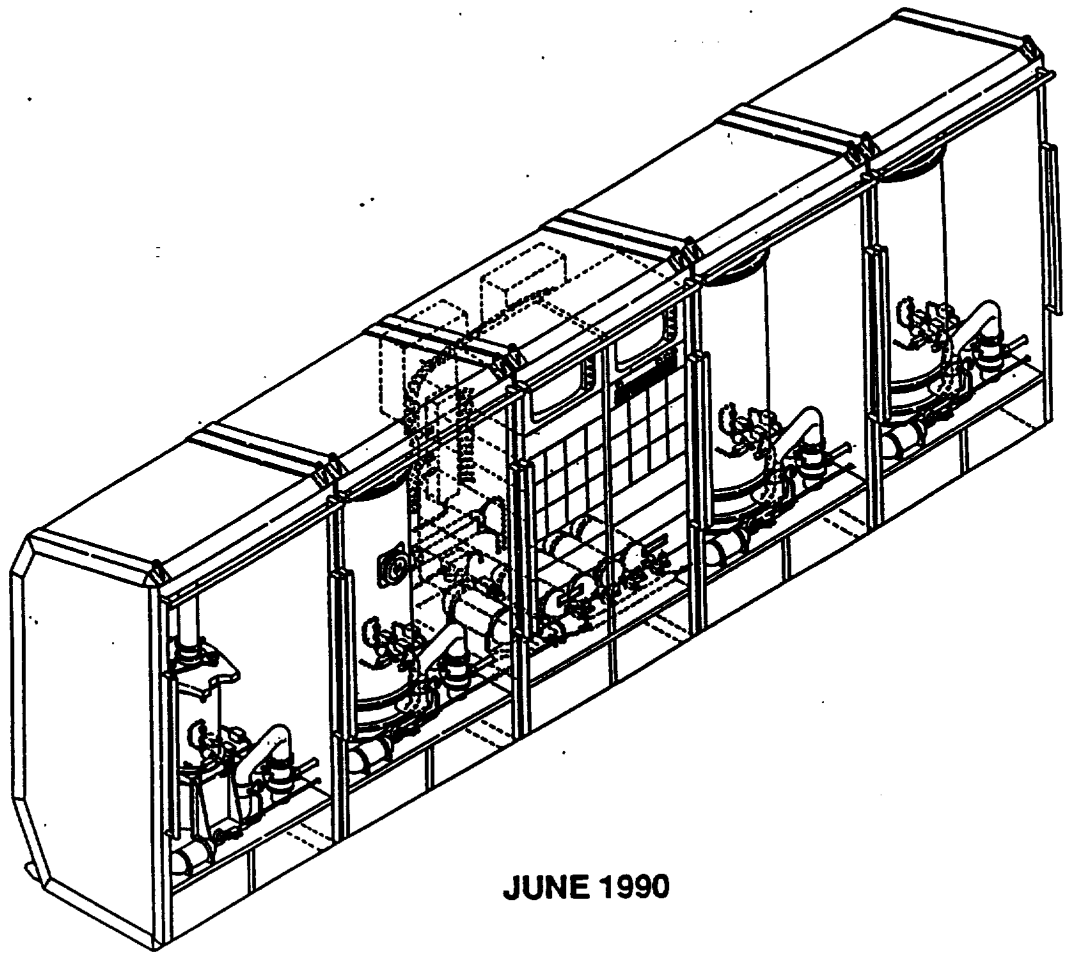
Based upon the changes in Space Station design/use configurations/concepts and the resultant downscaling of the safety-related tasks, it was determined that an attempt at this time to develop a plan as originally described above would be impractical. Rather, it was decided to develop concepts upon which detailed plans will be based at a later date when configurations and concepts will be better defined. Toward this end the following listed concepts have been developed:

1) SSFF Configuration and Maintenance Control Concept;
2) SSFF Safety Verification Concept;
3) SSFF Functional Verification Concept

DATA REQUIREMENT (DR) - 2

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

SSFF-PSA-001



JUNE 1990

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SSFF-PSA-001
June 1990

SPACE STATION FURNACE FACILITY
(SSFF)
PRELIMINARY SAFETY ANALYSIS

June 1990

Space Programs Division
Teledyne Brown Engineering
300 Sparkman Drive
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Preliminary Safety Analysis

June 1990

SSFF-PSA-001

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FOREWORD

This document provides Data Requirement (DR) - 2, Preliminary Safety Analysis, for the Space Station Furnace Facility Study performed under NASA Contract NAS8-38077. The report was prepared by Teledyne Brown Engineering, Huntsville, Alabama, for the NASA/Marshall Space Flight Center.

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1.0 INTRODUCTION

A Preliminary Safety Analysis (PSA) is being accomplished as part of the Space Station Furnace Facility (SSFF) contract. This analysis activity is intended to support SSFF activities by analyzing concepts and designs as they mature to develop essential safety requirements for inclusion in the appropriate specifications, and designs, as early as possible. In addition, the analysis identifies significant safety concerns that may warrant specific trade studies or design definition, etc.

The analysis activity to date concentrated on hazard and hazard cause identification and requirements development with the goal of developing a baseline set of detailed requirements to support trade study, specifications development, and preliminary design activities. The analysis activity will continue as the design and concepts mature.

Section 2 defines what was analyzed, but it is likely that the SSFF definitions will undergo further changes. The safety analysis activity will reflect these changes as they occur.

The analysis provides the foundation for later safety activities. The hazards identified will in most cases have Preliminary Design Review (PDR) applicability. The requirements and recommendations developed for each hazard will be tracked to ensure proper and early resolution of safety concerns.

1.1 PURPOSE

This document presents the results to date of the PSA. At this point, emphasis is on hazard identification and requirements development as stated above. Therefore, the format used for hazard presentation in this PSA was developed specifically to illustrate requirements derivation as clearly as possible.

1.2 SCOPE

The PSA effort applies to all identified SSFF elements. The PSA addresses SSFF concepts, and will eventually address GFP, related software, and conceptual ground and flight operations including integration, transportation to orbit, assembly, checkout, operation and maintenance as these activities and elements are identified. This document presents interim results of the PSA within this scope. The scope of this interim effort was driven directly by the corresponding stage of SSFF preliminary design development concepts. Section 2 summarizes the SSFF element details available for this interim PSA effort.

The safety analysis activity will continue after the submittal of this document to support the remainder of the contracted SSFF activities. New recommended requirements identified will be implemented in the appropriate specifications and the design. Major findings of immediate importance to NASA will be documented in correspondence. Otherwise, no further external documentation of SSFF safety analysis results is planned at this time.

1.3 APPROACH

The current configuration is analyzed for hazards in a top-down manner. Energy sources, hazardous functions, and hazardous operations are systematically analyzed to derive a list of inherent hazards. Once the hazards are identified, specific potential hazard causes are determined based on known subsystem designs and operating scenarios. Lessons learned from previous programs and related analyses (e.g., Spacelab and FMEA) will also be used to generate or add to the list of causes as necessary.

A control or a set of controls is necessary to adequately control the hazard for each potential hazard cause. These controls (requirements) may affect one or more subsystems or result in interface constraints. For this PSA, each cause was initially reviewed against current Space Station and NSTS requirements. The three top safety requirements documents used were:

a. SS-SRD-0001, Section 3, "Space Station Systems Requirements," On-Orbit

b. NHB 1700.7B, "NASA Safety Policy and Requirements for Payloads Using the STS"

c. KHB 1700.7A, "STS Payload Ground Safety Handbook." (Ground and GSE requirements will be assessed and added later.)

2.0 ANALYZED CONFIGURATION

The purpose of this section is to identify what was analyzed. Descriptions are provided to give the reader a clear understanding of the elements and subsystems that were covered and their key features. A complete description of the analyzed configuration is beyond the scope of this document. Readers of this document familiar with SSFF could proceed directly to section 3 for the results of the PSA and refer back to this section when questions on analysis scope, etc., arise.

The SSFF configuration analyzed consists of six major elements:

- Furnace Core
- Advanced Automated Directional Solidification Furnace (AADSF)
- Crystal Growth Facility (CGF)
- Hot Wall Float Zone Furnace (HWFZ)
- Metals and Alloys Solidification Apparatus (MASA)
- Visibly Transparent Furnace (VTF).

The following sections briefly describe these elements and some of the other relevant SSFF subsystems.

2.1 SPACE STATION FURNACE FACILITY

Teledyne Brown Engineering (TBE) has begun work on the conceptual design of the SSFF. The SSFF is a multiuser facility capable of supporting a wide variety of experimentation in solidification physics and crystal growth. The preliminary definition of this facility has defined a variety of unique furnace modules which can be integrated into a common support system and structure for mission-particular experimentation. The SSFF will occupy the volume equivalent to five Space Station Freedom (SSF) racks. Of this five-rack equivalent volume, one of these racks will consist of the Furnace Core (Avionics, etc.), and the other four will be dedicated to the Furnace Modules. The Furnace Core is the control center for the functionally diverse Furnace Modules. The Furnace Core will provide the resources required by the Furnace Modules. The Furnace Modules perform the scientifically unique function required to achieve the overall objectives of the SSFF. They are the experiment-specific elements of the SSFF. There are several candidate furnaces identified for the SSFF, including (primary consideration for analysis purposes) but not limited to the following:

- AADSF
- CGF
- HWFZ
- MASA
- VTF.

Other Furnace Modules will be designed and utilized over the life of the SSFF. However, this Furnace Module set should serve as an adequate reference payload set that will provide a comprehensive set of performance requirements for the SSFF Furnace Core. The CGF is planned to operate in at least four different configurations. These include the High Temperature Gradient Directional Solidification Furnace (HTGDSF), the Low Temperature Gradient Directional Solidification Furnace (LTGDSF), the Vapor Crystal Growth Furnace (VCGF), and the Programmable Multizone Furnace (PMZF).

2.1.1 Advanced Automated Directional Solidification Furnace (AADSF)

TBD

2.1.2 Crystal Growth Furnace and Related Concepts

The CGF, as designed for Spacelab, is a complex system of separate but integrated components. The CGF is a SSF precursor experiment, because it will be flown in the shuttle-based Spacelab module before assembly of the station. The interfaces will change for the SSF version of the CGF. Also, the SSFF Furnace Core will eliminate the need for some of the CGF subsystem components. These design and interface issues will be detailed more thoroughly in the "Conceptual Design" section of this report.

It is assumed that the science requirements for the SSF will be similar to those for Spacelab missions as they pertain to the CGF. This is because the CGF is designed to meet a specific set of science requirements, and significantly modified science requirements would most likely necessitate major design changes. The CGF science objectives for the SSFF era of spaceflight will be only moderately upgraded from those used for Spacelab. These science objectives are obtained from the document entitled "Reconfigurable Furnace Module Design Description," TBE document SP-DOC-6073. The Reconfigurable Furnace Module (RFM), shown in Figure 2.1-1, is the Furnace Core located within a modified Experiment Apparatus Container (EAC). The RFM is the element that best reflects the science objectives of the CGF. The primary function of the CGF is the microgravity processing of semiconductor materials, which is achieved by applying the appropriate thermal profile to a sample to accomplish directional solidification. The following items are the major objectives of this research:

- To isolate and study gravity-dependent and gravity-independent variables during the controlled solidification of electronic materials
- To produce crystals with reduced defect densities by growth in a microgravity environment.

The CGF is designed with independent thermal control of both the hot and cold zones in the classical Bridgman-Stockbarger furnace configuration and can be reconfigured or modified for vapor crystal growth or programmable multizone operation. The Bridgman-Stockbarger version can be configured for high temperature gradient directional solidification or low temperature gradient directional solidification depending on the length of the adiabatic zone. The addition of spacers and changes to the hot and cold zone temperatures permit varying of the gradients. VCG and PMZF will require much more significant modifications.

The CGF will have the capability of repeated interface demarcation during processing through either mechanical or Peltier pulsing.

Several types of semiconductor materials will be flown as sample materials in the CGF. These materials include, but are not limited to, alloys in the Cd-Te system, germanium alloys, and GaAs.

The following paragraphs describe three different CGF operational configurations, the HTGDSF and LTGDSF, VCGF, and PMZF.

2.1.2.1 <u>High Temperature Gradient and Low Temperature Gradient Directional Solidification Furnaces</u> - The HTGDSF and LTGDSF CGF design consists of three distinct components, the Hot Zone, the Adiabatic Zone, and the Cold Zone. The use of three separate stand-alone components allows for rapid reconfiguration to suit the needs of the various users. Reconfiguration of the

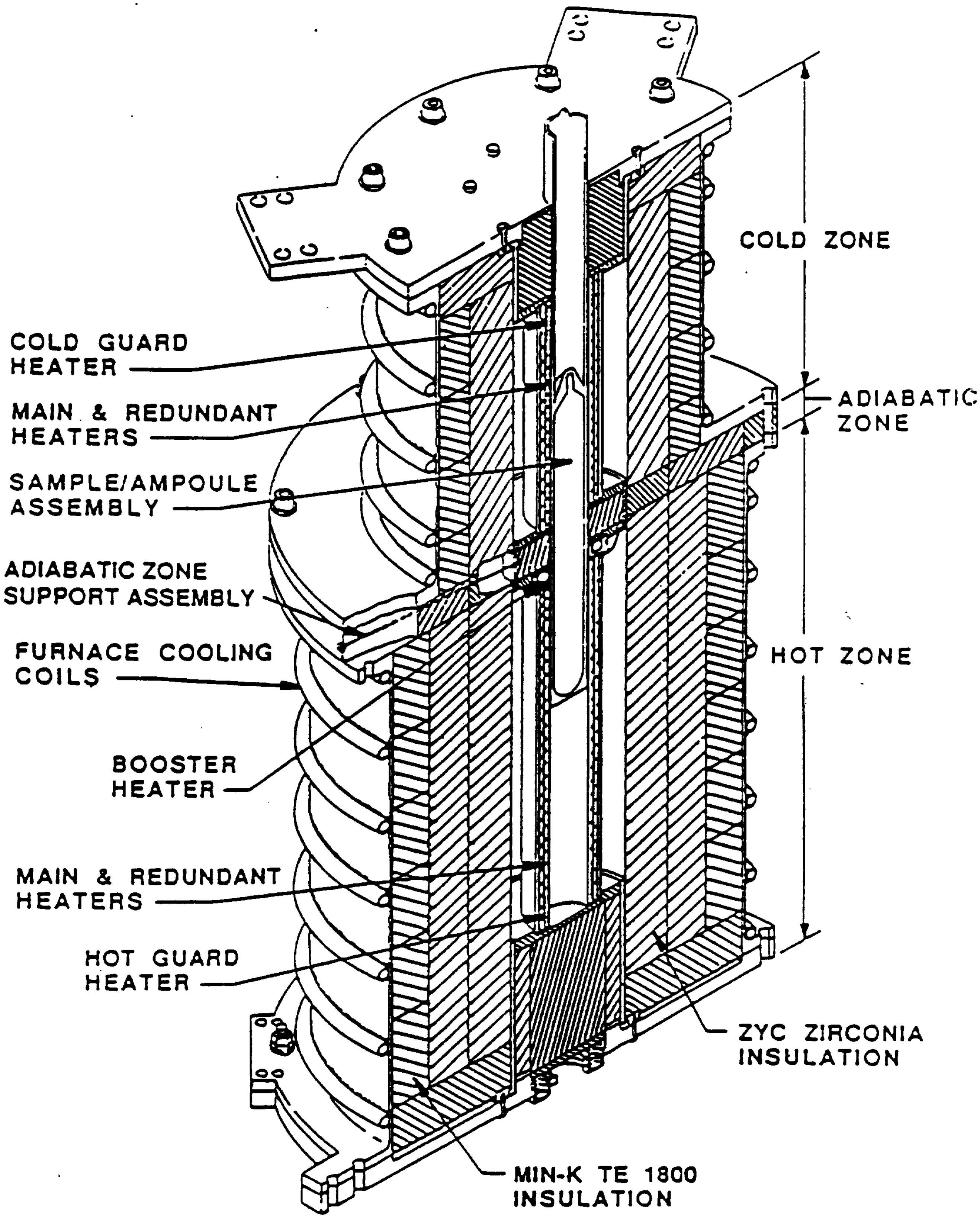


FIGURE 2.1-1. CGF RECONFIGURABLE FURNACE MODULE

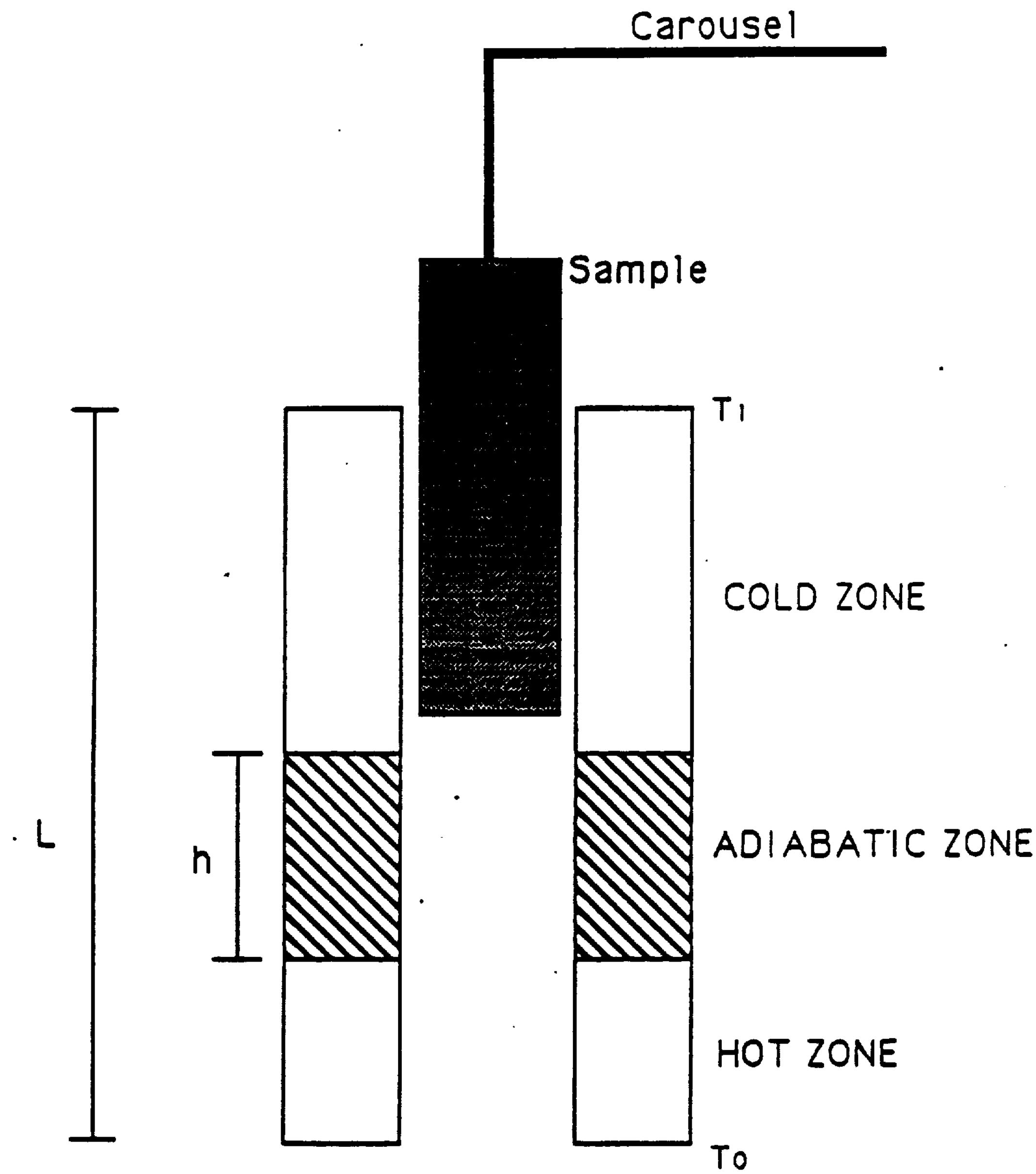
adiabatic zone allows different thermal gradients to be achieved, as shown in Figure 2.1-2. It was noted previously that the SSFF will consist of the Furnace Core and a selected set of Furnace Modules. The functional elements include the following units:

- Integrated Furnace Experiment Assembly (IFEA)
- Environmental Control System
- Power Distribution System (PDS)
- Command and Data Acquisition System (CDAS)
- Power and Signal Conditioning System (PSCS)
  (Recently separated into two units)

These systems-level boxes or units perform the specific functions that are required for all aspects of this type of microgravity crystal growth. The IFEA consists of the RFM, the Furnace Translation System (FTS), the Sample Exchange Mechanism (SEM), and the associated structural support, all enclosed within a modified EAC. This exact unit makes up the majority of the SSFF/CGF Furnace Module. However, the CGF Furnace Module will include other functional units that are not planned to be provided by the SSFF Furnace Core. It is the identification of these functional interfaces that constitutes the conceptual design of the SSFF.

The conceptual design of the SSFF/CGF Furnace Module requires a detailed system-level assessment of the CGF as designed for Spacelab. Those functions that are common to all Furnace Modules will be performed by the SSFF Furnace Core. The remaining functions and hardware elements will be classified as the Furnace Module. The SSFF Furnace Core will be required to perform the functions of the PDS, the CDAS, the Environmental Control System, and some functions currently performed by the Power Conditioning System. The CGF Furnace Module will consist of the IFEA, the Signal Conditioning System, and a portion of the Power Conditioning System.

The utilization of the IFEA as the heart of the SSFF/CGF Furnace Module is obvious from its design and application in the Spacelab version of the CGF. However, the rationale for transfer of the Signal Conditioning System and a portion of the Power Conditioning System to the Furnace Module classification may not be so obvious. The reason for this classification choice is



$\Delta T = T_1 - T_0$

Gradient= $\Delta T/h$

h can be shortened or increased with spacers , and T_0 can be raised or lowered to achieve ΔT desired

FIGURE 2.1-2. ADIABATIC ZONE RECONFIGURATION that the conceptual design of the SSFF Furnace Core does not include provisions for unique and specialized signal conversion; thus, this function should be performed by a component of the Furnace Module.

Several interfaces are changed as a result of this functional rearrangement of the existing CGF. In particular, the new interfaces of the SSFF Furnace Core to the CGF Furnace Module will require at least eight break-points. The operational issues associated with this concept will be discussed further in the "Technology Risk" section of this report.

Another design-related issue is the structural support and mounting provisions for the CGF Furnace Module. The plan for mounting of the IFEA in the Spacelab Module is a vertical installation on a special structure at a Spacelab rack location, but not inside a Spacelab rack. Volumetric considerations made this necessary. A top-level volumetric assessment of the SSF rack indicates that the IFEA EAC would fit inside; however, the clearance would be only 7.4 in. This would not be enough clearance for sample changeout. However, the in-rack mounting base for the EAC could be designed to tilt out, thus providing access to the sample insertion port and the capability for ampoule exchange. The only other alternative is to provide the same type of structural accommodations as the Spacelab version of the CGF. It is not likely that the same mounting base could be used in a SSF rack location because of the inherent differences between SSF and Spacelab racks. A modified Spacelab EAC mounting plate would be required for SSF if this mounting configuration concept is used.

The resource requirements for HTGDSF and LTGDSF in the CGF Furnace Module include a wide variety of resources that are typical of materials processing experiments. The primary difference between the Spacelab version of the CGF and the SSFF/CGF Furnace Module is the source of the payload resources. In the Spacelab version of the CGF, these resources will be supplied directly from the Spacelab carrier; however, the SSFF version of the CGF will use the Furnace Core, which manages the resources provided by the carrier [i.e., the United States Laboratory (USL) module] and controls the distribution of these resources to the various Furnace Modules.

In general, the resources provided to payloads by the USL module are similar to those provided by the Spacelab module to its payload elements.

The USL module will have slightly increased capabilities over the Spacelab module (other than crew time); therefore, the SSF should be capable of providing almost all the necessary resources for the CGF Furnace Module. The availability of the following resources needs to be verified for future versions of this report.

- Argon distribution or bottles in the USL
- Determination of adequate water flow for thermal control
- Determination of adequate avionics air flow for thermal control.

Table 2.1-1 is a summary of the power and data interface requirements for the CGF Furnace Module.

2.1.2.2 Vapor Crystal Growth Furnace - The CGF can be configured for vapor crystal growth quite easily. The gradients provided can drive the mass transfer from a source crystal in the hot zone to a seed or sting in the cold zone. Modification is primarily to the ampoule. Imaging may require much more significant modifications as will be discussed later. The following report is part of an effort being performed by TBE, which deals with Materials Processing in Space (MPS) research for the SSFF contract. This is a preliminary conceptual design of the HWFZ.

The use of the vapor crystal growth method (or chemical vapor transport) as a method of production of semiconductor crystals in a low-g environment allows scientists to better study the effects of gravity-induced convection on vapor mass transport between the source and crystal. The vapor crystal growth process involves establishing a thermal gradient between a source material and a seed crystal. The thermal gradient produces a composition gradient between the source and seed. Crystal growth at the seed crystal occurs because of the vapor transport of material from the hot source material to the cooler seed crystal. The low-g environment reduces or eliminates convection cells in the vapor field, maintaining a lamellar flow field under diffusion-controlled conditions.

The VCGF module will be designed to perform crystal growth for technologically important semiconductor materials using the vapor crystal growth technique. A major benefit of vapor crystal growth processing is the production of high-quality, dislocation-free crystals of elemental or lightly doped

TABLE 2.1-1. CGF DATA AND POWER INTERFACES

INTERFACE	QUANTITY
Analog Inputs	48
Analog Outputs	8
Discrete Inputs	64
Discrete Outputs	48
28 Vdc Power Lines	32
Variable Power Lines	18
Serial Communications	0

semiconductors. The space-based furnace will also improve the scientific understanding of the role of convective flows in Earth-bound growth methods.

The furnace module will be composed of five independently controlled heater zones to control overpressures in multicomponent systems and to provide the shallow temperature gradient required by the vapor diffusion process. Ampoule wall temperature will need to be controlled to prevent multiple nucleation of the source material on the ampoule walls. The module shall also be designed to allow translation of the heater module over the stationary sample ampoule to maintain growth interface supersaturation.

The vapor crystal growth module is currently defined as being a modification of the Crystal Growth Furnace. The modification required for vapor crystal growth is the replacement of the RFM with an RFM designed specifically for vapor crystal growth. The "standard" RFM is configured as a two-zone furnace for directional solidification using the Bridgman-Stockbarger technique. At least five zones are necessary to provide the temperature control required for the vapor crystal growth process. The zone temperatures will be programmed to act as three distinct temperature regions; the low-temperature area, the booster heater area, and the high-temperature area. It is estimated that the power requirements will be similar if not somewhat less then the standard CGF configuration. No special consumables are required for the vapor crystal growth RFM.

The incorporation of devices for optical or thermal imaging of the growing crystals will require an extensively modified RFM and modifications of the IFEA. Viewing must be limited to the low-temperature zones (crystal growth zone) only because of the high temperatures of the other zones. The crystal growth zone has a maximum temperature of 1100 °C, which is also the maximum temperature of currently available visibly transparent materials such as quartz or sapphire. Quartz may be limited to lower temperatures depending on the vapor pressures inside the ampoule. There may also be a problem with cold spots at the window positions.

The requirements that necessitate furnace modification for vapor crystal growth are shown in Tables 2.1-2, 2.1-3, and 2.1-4.

2.1.2.3 Programmable Multizone Furnace - The CGF can be configured to a PMZF with some major modifications. The PMZF, shown in

TABLE 2.1-2. FURNACE PHYSICAL PARAMETERS

Sample Size:	
Outer Diameter	0.5 - 3.50 cm
Total Processable Length	8.0 - 25.0 cm
Heated Cavity Length	35.0 cm
Gradient Zone Length	0.50 - 4.00 cm

TABLE 2.1-3. FUNCTIONAL AND PERFORMANCE REQUIREMENTS

Low Temperature Zone	200 - 1100 °C
High Temperature Zone	200 - 1600 °C
Booster Heater Zone	200 - 1650 °C
Heatup and Cooldown Rate	TBD
Translation Capability	
Processing Rate	0.01 to 10.0 mm/h
Control Range	35.0 cm

TABLE 2.1-4. RESOURCE REQUIREMENTS

Power requirement	1500 W max. 900 W avg.
Volume	0.56 m^3
Mass	190 kg
Consumables	Argon Approx. 0.2 m^3/run

Figure 2.1-3, is a 30-zone furnace that uses computer control to sequentially control heater elements in the furnace so that a temperature gradient can be moved through the sample without using a translation mechanism. The PMZF does not have an adiabatic zone, and it requires individual control of each element in the furnace. Therefore, the PMZF will require complete modification to the IFEA. The PMZF is a project being managed by Lewis Research Center (LeRC). The PMZF will be designed to directionally solidify bulk single crystals in the microgravity environment of space. While the LeRC project is currently in a very early stage of development, this report is based on information obtained from Bruce Rosenthal, the PMZF project engineer at LeRC, and data on other furnaces currently under development, coupled with the science requirements in the SCRD.

The PMZF will be designed to accommodate alloys, semiconductors, and other materials that require controlled low-temperature gradients between two nearly isothermal temperature regions. The PMZF will be a resistance-heated furnace capable of producing samples approximately 3 cm in diameter and 30 cm in length. The design will allow for the adaptation to the individual user's samples and be capable of maintaining a solidification front in an optimum position for obtaining a planar interface.

The elimination of gravity-driven convection in space makes it an ideal environment for processing single crystals. This technique is vital to the design and fabrication of modern electronic devices since the primary objective is to produce materials that are homogeneous in composition and have perfect crystal structures.

The principal goal in bulk crystal growth techniques is to generate a thermal gradient to produce a planar liquid-solid interface in the sample and to translate this interface along the length of the sample material to yield a single crystal. The Bridgman-Stockbarger thermal configuration limits growth to only one direction using linear temperature gradients. The translation of the temperature gradients in the conventional Bridgman furnaces is usually performed by moving the furnace in relation to the sample and vice versa. This translation may cause disturbances in the growth front of the crystals, and elimination of these disturbances would allow more nearly homogeneous crystals to be produced. The PMZF will reduce these disturbances.

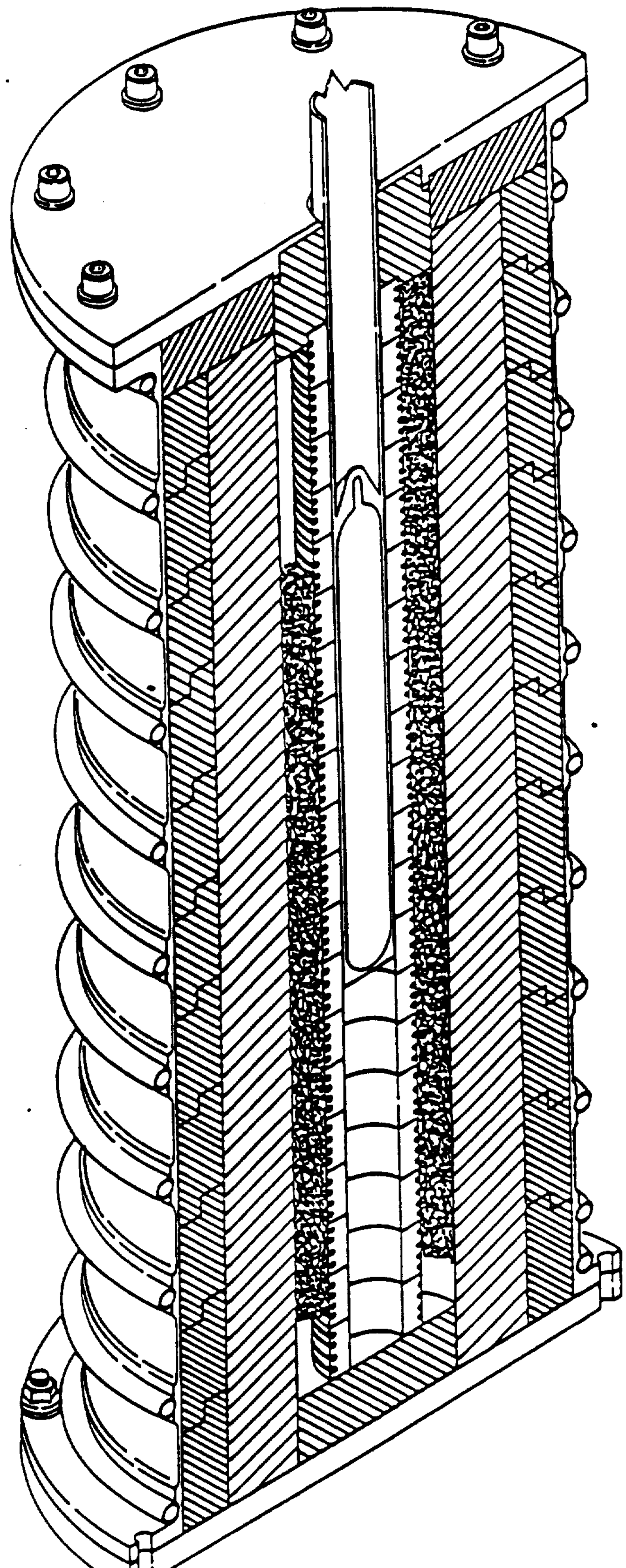


FIGURE 2.1-3. PROGRAMMABLE MULTIZONE FURNACE (Sheet 1 of 2)

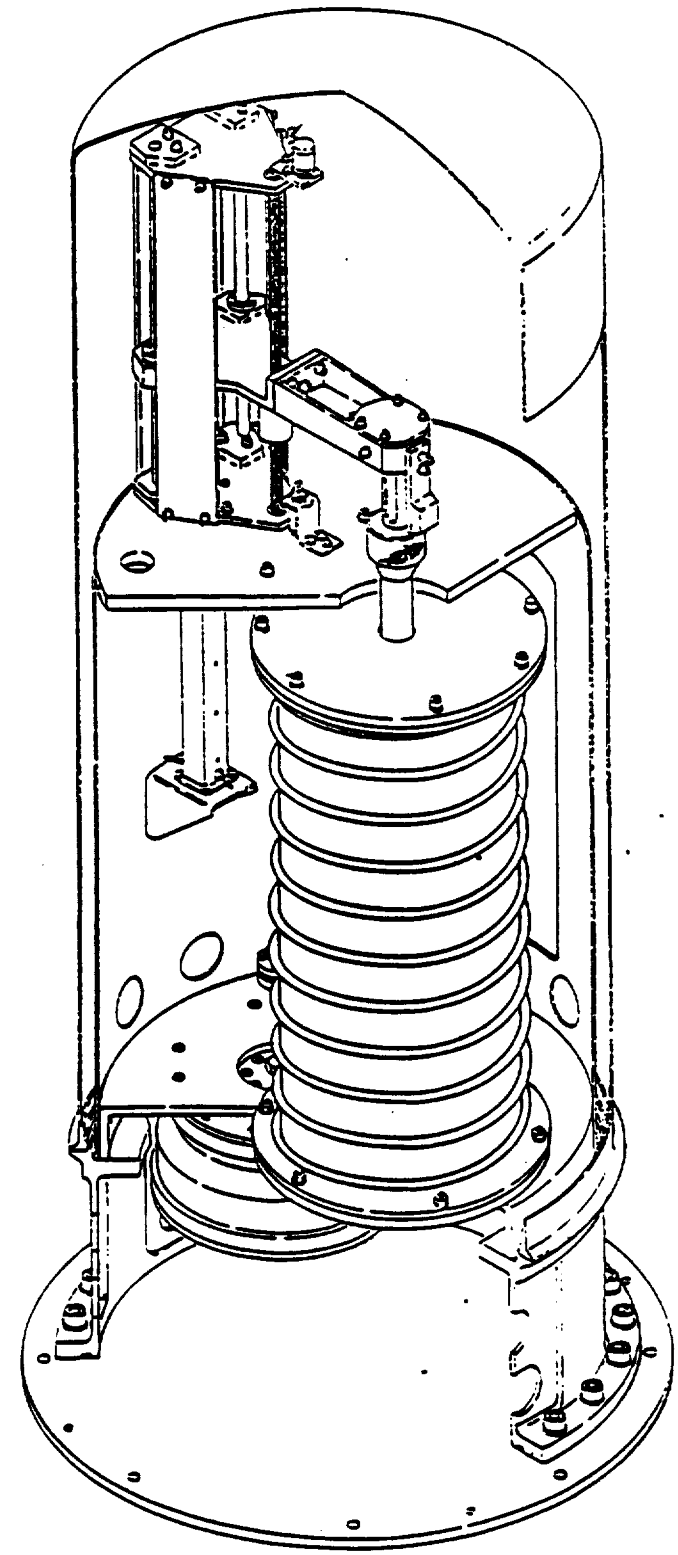


FIGURE 2.1-3. PROGRAMMABLE MULTIZONE FURNACE (Sheet 2 of 2)

As stated earlier, the PMZF produces temperature gradients through a series of connected temperature zones and translates these gradients by coordinated sequencing of the zone temperatures. Therefore, the CGF configuration would need to be drastically modified to incorporate this method. The magnitude of the temperature gradient must be limited for many materials because of thermal stress effects, and, therefore, a very low growth velocity must be employed. The PMZF version is limited to low-temperature gradients because of the indirect furnace-to-sample thermal coupling needed to blend the discrete zones. The PMZF will consume more power than customary Bridgman furnaces because every zone must be capable of providing the high cooling rates needed to achieve the maximum desired temperature drops. This high heat loss could restrict SSFF applications. The ability of the PMZF to translate its thermal gradients through the use of a control mechanism would eliminate the need for a large furnace translation device. Typical power consumed by the CGF translation system is 350 W/run. The PMZF will only require a motor to insert and withdraw the ampoule from the furnace, and, therefore, much less power will be required to provide the effect of translation.

The PMZF will require several supporting subsystems. These may include, but are not limited to, the following:

- Control System
- Power Distribution System
- Thermal Control System
- Ampoule Leak Detection System
- Data Acquisition System
- Ampoule Insertion and Removal System
- Purge/Vent System
- Experimental Apparatus Container.

The PMZF will contain between 20 and 30 individual heating zones, and each zone will be approximately 1 in. high. With the addition of booster heaters at the top and bottom of the furnace to reduce heat loss, the furnace will be approximately 40 in. thick. The temperature range of the furnace will be 0 to 1500 °C. Thermal gradients achieved by the furnace should be ≤30 °C/cm. The maximum gradient velocity achieved in a similar furnace in an RE-717 report titled "Developmental Testing of a Programmable Multizone

Furnace," was 10 in./h. Each zone of the furnace will contain two platinum/rhodium heating elements that were chosen for their high temperature strength and oxidation resistance.

Temperature accuracy is a critical factor in the design of the PMZF. Without highly accurate thermocouples, the desired temperature gradients and their motions cannot be obtained. The properties that are essential to thermocouple performance depend to a large extent on the temperature range in which the furnace is to operate. Type K thermocouples (Chromel-Alumel) can be used from 0 to 1250 °C. Type S thermocouples (platinum-platinum/10% rhodium) can be used from 0 to 1450 °C. Type B thermocouples (platinum/30% rhodium-platinum/6% rhodium) can be used from 800 to 1700 °C. All three of these exhibit good oxidation resistance in their operating range as well as high EMF output over that range. However, outside their temperature range and as they age, these thermocouples will display some degradation in performance. Therefore, Type S thermocouples would be best suited for SSFF applications. The inability to determine the exact temperature at a zone will prevent the establishment of an exact gradient.

At full power, each element of the RE-717 furnace required 132 W. Therefore, each zone would require 264 W, and, with up to 34 zones including booster zones, the entire furnace would require approximately 9 kW. This measurement was based on a voltage at the heating element of 2.2 Vac and a measured element current of 60 A during full furnace power. If only 8 zones (12 with boosters) were used in the furnace, about 3.1 kW is required. Time proportioned (duty cycle) power control was used, which pulses the power to the heating elements at a rapid rate so that an average power level was achieved over time. According to RE-717, there is no reason, other than cost, why another power control method such as voltage proportionation cannot be used to reduce the peak-power demand.

The thermal averaging, which will be needed to smooth the effect of discrete heating zones, will mean that cooling cannot be localized. In the test furnace used by RE-717 with a 0.5-in. diameter sample, temperature gradients up to approximately 75 °C/in. were achieved with a stainless steel sample and 30 °C/in. with a copper sample. The magnitude of the gradient is limited by the amount of axially conducted heat that can be lost radially. Minimum gradients are limited by the accuracy of the control system since the gradient produced is no better than the temperature sensors used to create it. Because of errors in the thermocouples, the lower limit would be approximately 6 °C/in. at 750 °C.

The gradient velocity's upper limit is dependent on the cooling rate of the zones, the operating temperature, the gradient magnitude, and the sample conductivity. Thermal gradient velocities of 10 in./h were achieved in the RE-717 furnace using low conductivity materials (<16 W/mC). The lower limit of the gradient velocity is dependent on the time-temperature stability and accuracy of the system. With room temperature changes of 5 °C in 5 h, a gradient of 20 °C/in., and 10 percent precision in gradient velocity, RE-717 achieved a lower limit of 0.075 in./h. The lower limit may be unacceptably high at low temperatures where temperature oscillations occur more frequently because of inadequate control resolution.

Resource requirements for the PMZF are shown in Table 2.1-5.

2.1.3 Hot Wall Float Zone Furnace

The use of the floating zone method as a technique for containerless processing of semiconductor materials in a low-g environment allows scientists to better study thermocapillary flows, meniscus shapes and stability, and transport processes. The floating zone crystal growth process involves passing a polycrystalline rod of sample material through a circumferential heat source which is above the melting temperature of the sample. As the rod passes through the heated zone, a molten zone forms just ahead of the heater and is resolidified into a single crystal rod at the rear of the heater. The shape of the molten zone is determined by the actions of the surface tension that holds the meniscus in place against gravitational and dynamic forces. As the force of gravity is reduced, the size of the molten section can be enlarged, and the meniscus will have a more desirable shape. The low-g environment will provide benefits to float zone processing as follows:

- Undistorted zones may be processed in materials with low surface tensions.
- Buoyancy-driven convection is reduced.
- Quiescent heating may be used to eliminate violent stirring associated with R-F heating.

TABLE 2.1-5. RESOURCE REQUIREMENTS

Power:	9 kW (34 zones) 3.1 kW (12 zones)	
Thermal Cooling:	8 kW (includes cooling for subsystems)	
Heated Cavity Control:	± 1% over length of zone	
Processing Gas: (purge/vent)	Argon	
Data: 30-zone furnace	Peak Rate	No. of Channels
IN:		
Analog (I/Fs):	0.03 Mbps	30
Digital (I/Fs):	0.03 Mbps	120
Serial (I/Fs):	0.03 Mbps	3
OUT:		
Analog (I/Fs):	0.1 Mbps	180
Digital (I/Fs):	0.1 Mbps	480
Serial (I/Fs):	0.1 Mbps	6

- Stoichiometry may be preserved by use of liquid phase encapsulants and pressurized growth chambers. This practice is normally used on Earth for Czochralski growth, but is not suited for float zone geometry in Earth's gravity.
- Modeling of heat flow may be tailored to produce optimum growth interface shapes.
- Surface tension will still present a problem but can be controlled by lowering axial gradients using liquid phase encapsulants or applying magnetic fields.

The HWFZ furnace module will be designed to perform zone purification/refinement and crystal growth in a hot wall chamber for technologically important materials using the float zone technique. One benefit of the float zone processing is the production of high-quality, dislocation-free crystals of elemental or lightly doped semiconductor materials. Also, this furnace can be used for purification and/or refinement of metals, alloys, and glasses. This is a result of a solidification front which passes down the length of the sample. As it does so, impurities present in the material cannot overcome the energy present at the solid-liquid interface and they are therefore pushed down the length of the sample. After several passes, the sample will be relatively free of impurities, except for one end which can be removed. The HWFZ will, in the future, have the ability to perform the following experiments:

- Float Zone Crystal Growth
- Float Zone Purification of Materials
- Directional Solidification
- Crystallization Phenomena Studies.

The HWFZ will allow for the characterization of Marangoni flows, driven by surface tension differences within the melt. The influence of the absence of buoyancy flows on the grown crystal and the characterization of Marangoni flows will be used to:

- Determine what improvements can be made in crystals grown in microgravity conditions as compared to crystals grown on Earth
- Predict the size limits (rod diameter and length) for which improvements can be expected

- Obtain better understanding of the relative roles of buoyancy and Marongoni flows in Earth-bound growth methods, such as float zone and Czochralski crystal growth of silicon and other materials.

The HWFZ furnace module will have up to five temperature zones to control the overpressures of multicomponent systems. It will be designed to provide peltier pulsing and mechanical pulsing to the translation system to demarcate the solid-liquid interface, and thermal and optical imaging devices to furnish real-time observations. The HWFZ module will be capable of providing precise control of heater elements, measuring and recording of the furnace temperatures, translation rates, and sample position relative to the furnace module. This allows larger diameter materials to be processed by keeping the feed and growth rods near the melting point. HWFZ processing requires both ends of the sample to be aligned relative to one another during processing. Therefore, this furnace module must utilize a sample translation device with differential feed-rod/growth-rod translation capability mounted to each end of the sample. The furnace module will also use a differential rate opposing direction sample rotation system. The sample rotation mechanism will be used to rotate the sample at a set rate during the process phase. Rotation of the sample is required to allow for a uniform distribution of heat during the process phase and for proper movement of the molten zone. The sample must be contained within a cartridge to prevent any evaporated or liquid sample material from coming into contact with the furnace core. A conceptual design of the HWFZ is illustrated in Figures 2.1-4 and 2.1-5.

The HWFZ furnace will require several supporting subsystems, which are listed below:

- Purge/Vent
- Experimental Apparatus Container
- Computer Control
- Sample Insertion/Removal
- Data Acquisition
- Leak Detection
- Power Distribution
- Thermal Control.

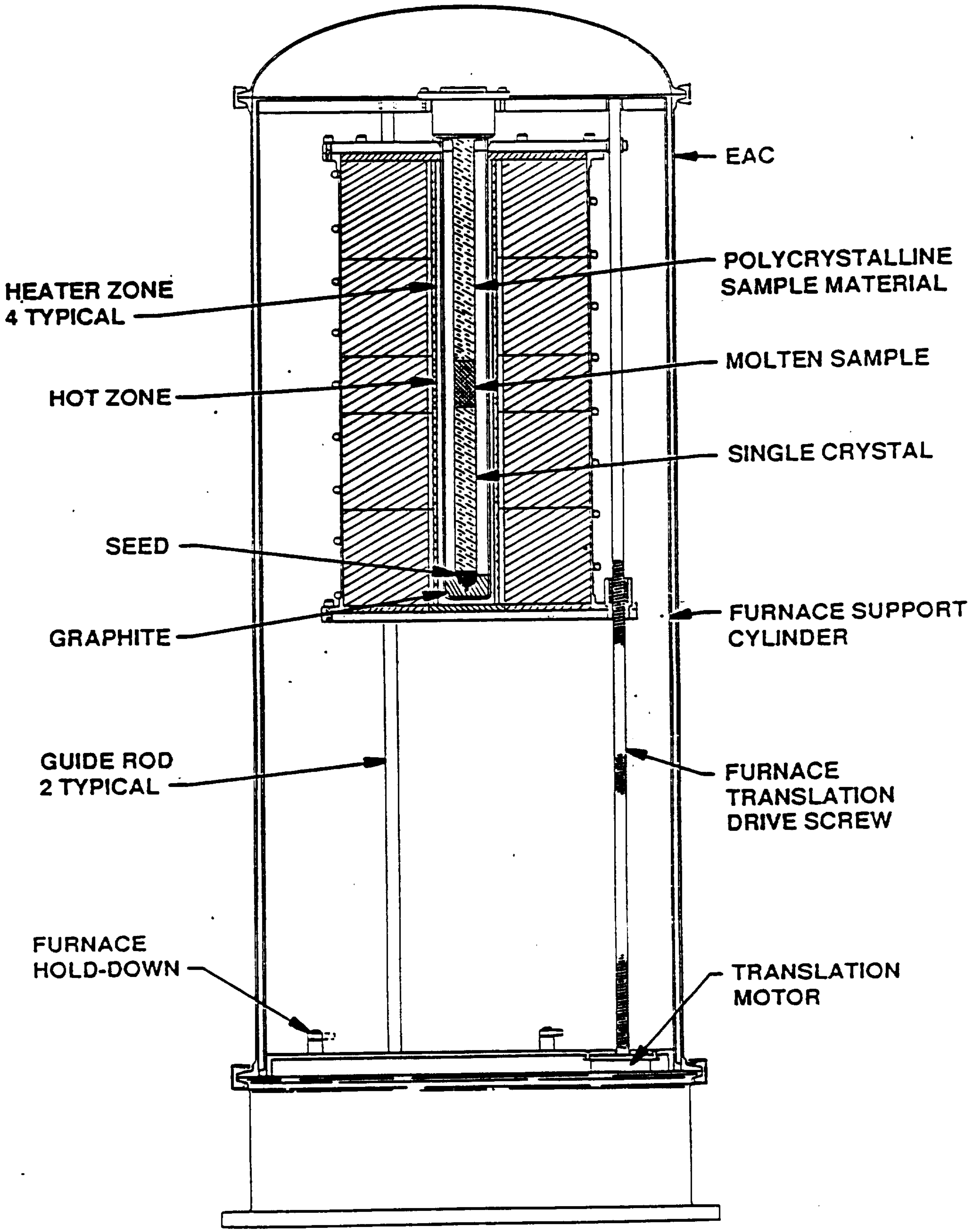


FIGURE 2.1-4. HOT WALL FLOAT ZONE FURNACE MODULE

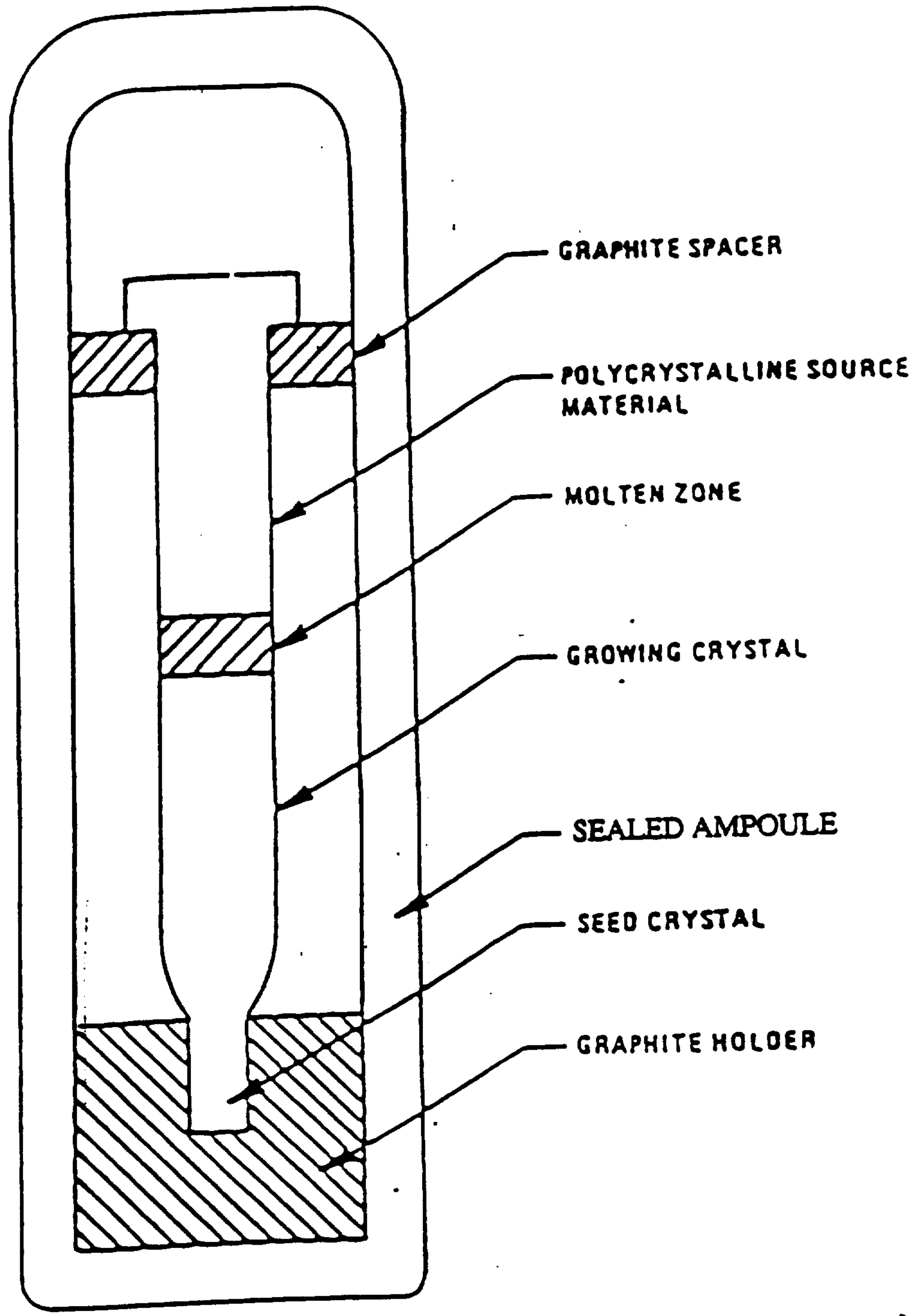


FIGURE 2.1-5. SAMPLE CONTAINER

The HWFZ furnace physical parameters, functional and performance requirements, and resource requirements are shown in Tables 2.1-6, 2.1-7, and 2.1-8, respectively.

2.1.4 Visibly Transparent Furnace

Current research in areas of high temperature crystal growth and directional solidification is usually limited to opaque furnaces to minimize heat losses. Because of this limitation, it is difficult to study the solidification process and the effect of processing parameters on interface morphology in real time. Science objectives on some experiments require active monitoring of the solid-liquid interface shape as a feedback loop to the process controller. Transparent furnaces allow the active monitoring of the interface shape and morphology for scientific study or process control.

The Visibly Transparent Furnace facility will be composed of the transparent furnace module, which will use the following SSFF subsystems:

- Temperature display system
- Video processing system
- Controller and data acquisition system
- Thermal control system interface
- Crew alert system
- Power conditioning and distribution.

2.1.4.1 Heating System - A conceptual design for the furnace core is illustrated in Figure 2.1-6. The thermal gradient is established by multiple heating element zones wound in a series of stacked quartz muffle tubes. The heater core will be composed of eight or more independently heated zones. The zones are separated by thin ceramic baffles, which prevent reflections between adjacent zones. It is estimated that the total power requirements for the heaters will be approximately 1,500 W. The total heater zone length will be 20 in. and the internal diameter of the hot zone will be 1.5 in. An alternate configuration using an insulated hot zone section is shown in Figure 2.1-7.

2.1.4.2 Translation System - The module should be designed for furnace zone translation over a stationary sample to minimize any accelerations imparted to the sample by drive mechanism noise or translation rate changes. Furnace translation also reduces the complexity of incorporating a sample

TABLE 2.1-6. FURNACE PHYSICAL PARAMETERS

<u>Sample Size:</u>	
Outer Diameter	0.50 - 3.0 cm
Total Processable Length	8.0 - 25.0 cm
Heated Cavity Length:	35.0 cm
Zone Length:	0.20 - 10.0 cm
<u>Digital Control Data</u>:	
RTDs	
Furnace Atmosphere	4
Coolant Water	4
Thermocouples	
Each heater element	4
Sample ampoule	4
Translation motors	2
Coolant loop	6
Pressure Transducers	
Coolant pressure drop	4
Vacuum gauge	2
Other Sensors	
Humidity sensors	4
Cartridge failure	4
Limit switches	5
Toxic offgas sensors	5
Motor drives	3
Resolution	0.1 °C
Number of Channels	53
Avg. Data Rate of sensors	5 samples/sec
Peak Data Rate (motor drives)	40,000 samples/sec
Video data rate	528 x 380 x 8 x 30 =48 Mbps

TABLE 2.1-7. FUNCTIONAL AND PERFORMANCE REQUIREMENTS

Experiment Timeline	Up to 90 days
<u>Heated Cavity Operating Range</u>	
Feed and growth zones	200 - 1200 °C
Hot wall zone	200 - 1600 °C
<u>Heated Cavity Control</u>	
Float Zone	TBD
Feed and Growth Zones	TBD
<u>Translation Capability</u>	
Rate	TBD
Differential feed-rod/growth-rod Translation Rate	TBD
<u>Rotation Capability</u>	
Differential Rate Opposing Direction	TBD
Cooling Requirements	TBD

TABLE 2.1-8. RESOURCE REQUIREMENTS

Power	1500 W avg.
	3100 W peak
Voltage	28 Vdc
Volume	.32 m^3
Mass	≈200 kg
Vacuum/Vent	10 E^{-3} Torr
Thermal Control	
Avionics Air	310 W
Cooling Water	2.8 kW
Consumables	
Inert Gas	Argon
Samples	TBD

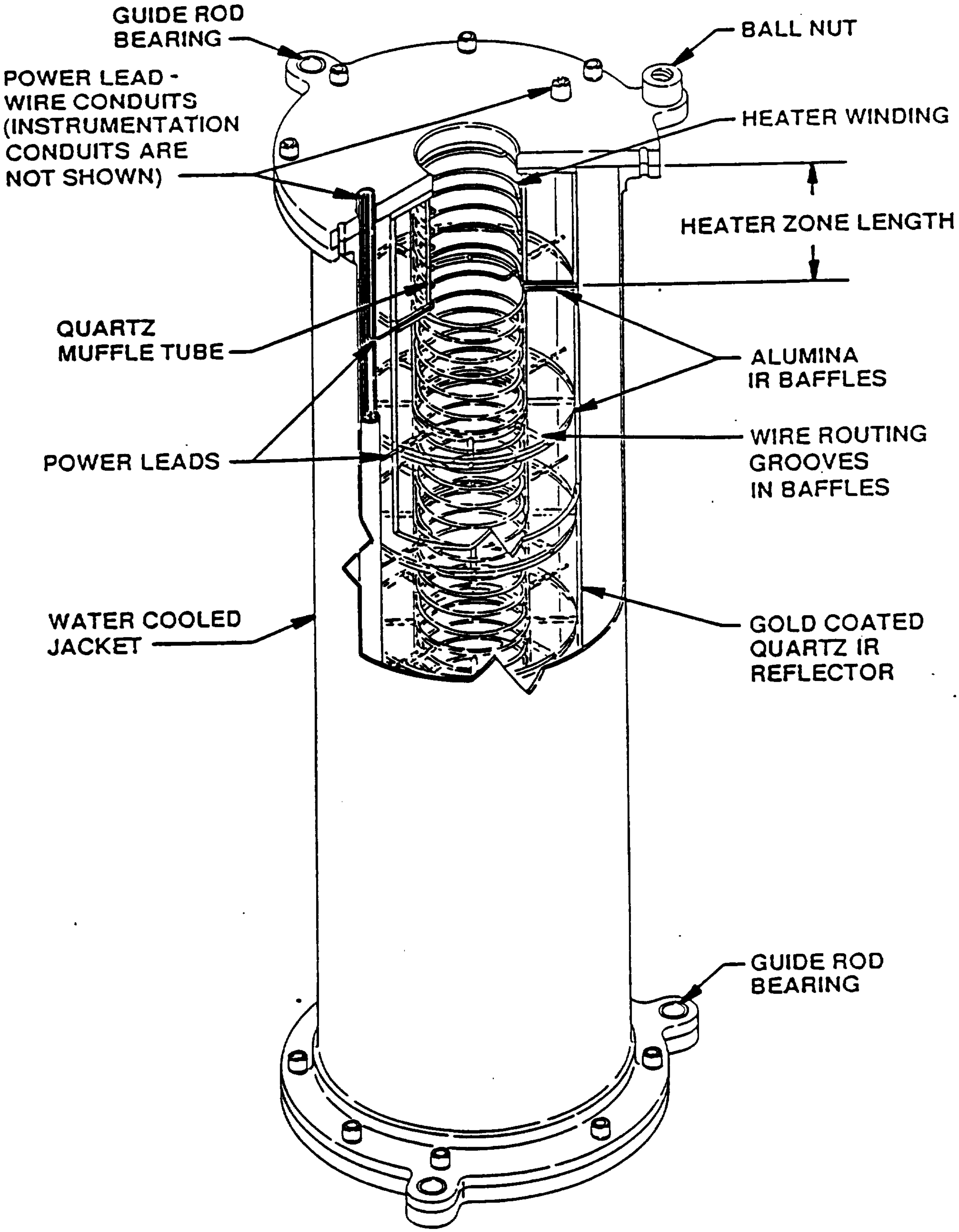


FIGURE 2.1-6. MULTIZONE TRANSPARENT FURNACE CORE

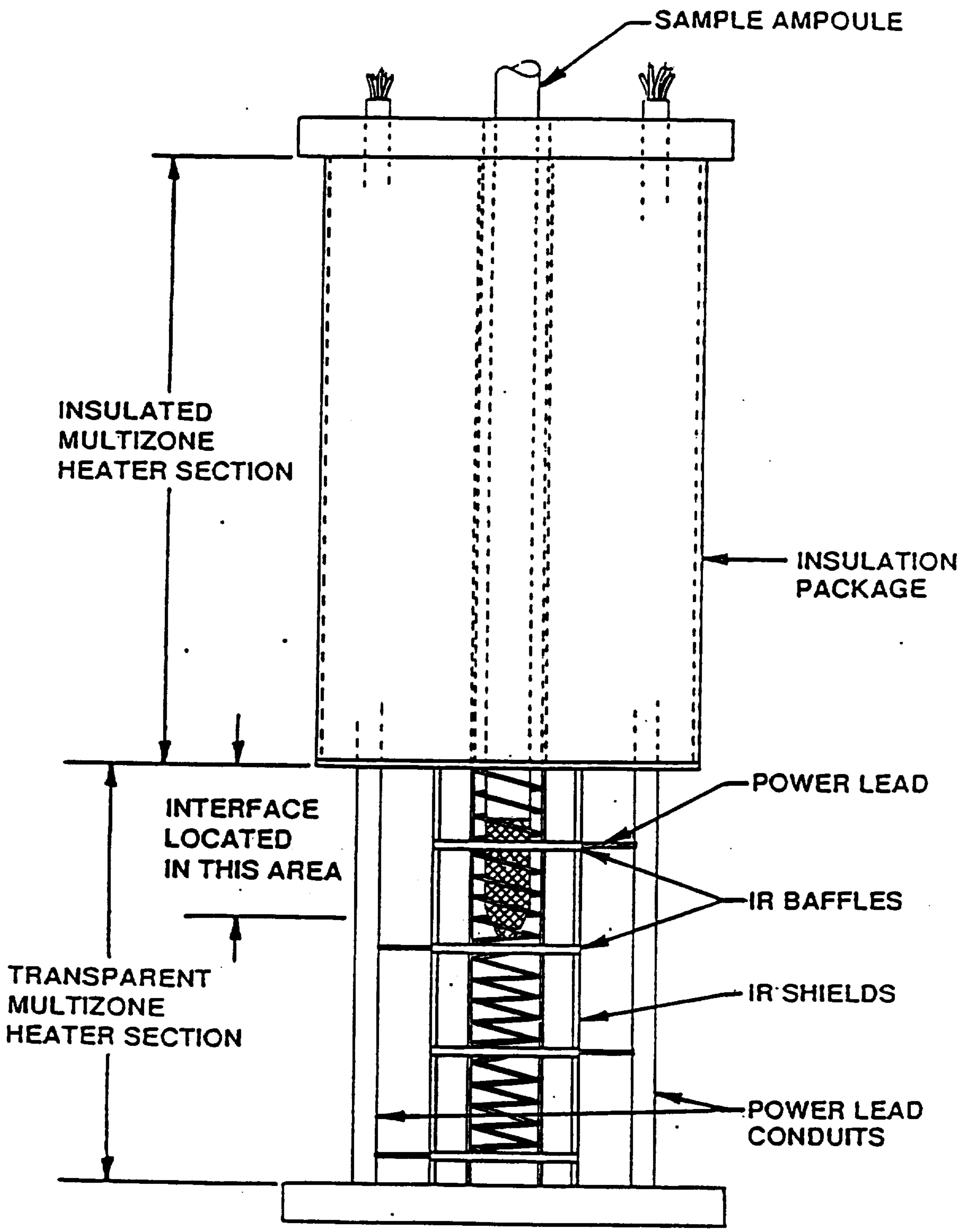


FIGURE 2.1-7. INSULATED HOT ZONE FURNACE CORE CONCEPT

agitation system. Translation of the furnace core requires a system to feed the power and instrumentation leads to the furnace core area during translation. The scheme envisioned for lead wire routing in this concept is shown in Figures 2.1-6 and 2.1-8. Both power and thermocouple leads are channeled through grooves in the IR baffles to conduits spanning between the furnace core endplates. Flexible umbilicals will then route the leads to the furnace module housing endplates. The drive system will employ a "traditional" lead screw and guide rod system. The translation system should have a step resolution of at least 1 micron. Translation rates will vary from 0.5 cm/day to 50 cm/day. Rapid translation capability is required. Microstepping capability is not required on the rapid translation motor.

2.1.4.3 Heat Shielding - An IR reflector or shield is considered to be a necessity on this type of furnace to conserve power. The shield used would probably be a gold-coated quartz tube, transparent to visible light, but reflecting IR.

2.1.4.4 Video System - The furnace will need to be enclosed by an additional vessel for safety (three levels of containment) and waste heat extraction. This will require the use of a video camera system for viewing the sample (as opposed to looking through three layers of windows from the outside). It is desirable to place the camera as close as possible to the sample ampoule in the event high magnification is required. Several options exist for placement of the camera with respect to the thermal cooling jacket. The first option places the camera inside the cooling jacket adjacent to the heater core. The optics and camera will require a thermal control system because of the proximity to the furnace core. The second option places the camera outside of the cooling jacket in the space between the jacket and the EAC. The camera will view the interface through a window in the cooling jacket. A third option, shown in Figure 2.1-8, places the cooling jacket on the translating furnace core. The camera will be located outside of the jacket and will view the sample through a window in the jacket. This option requires that an additional level of containment be added since the cooling jacket no longer serves this purpose due to the exposed ends of the ampoule. This configuration may also require a booster heater around the viewing window to prevent heating dissymmetry. This configuration also places the camera further from the furnace. The containment could be in the form of extension bellows on the ends of the

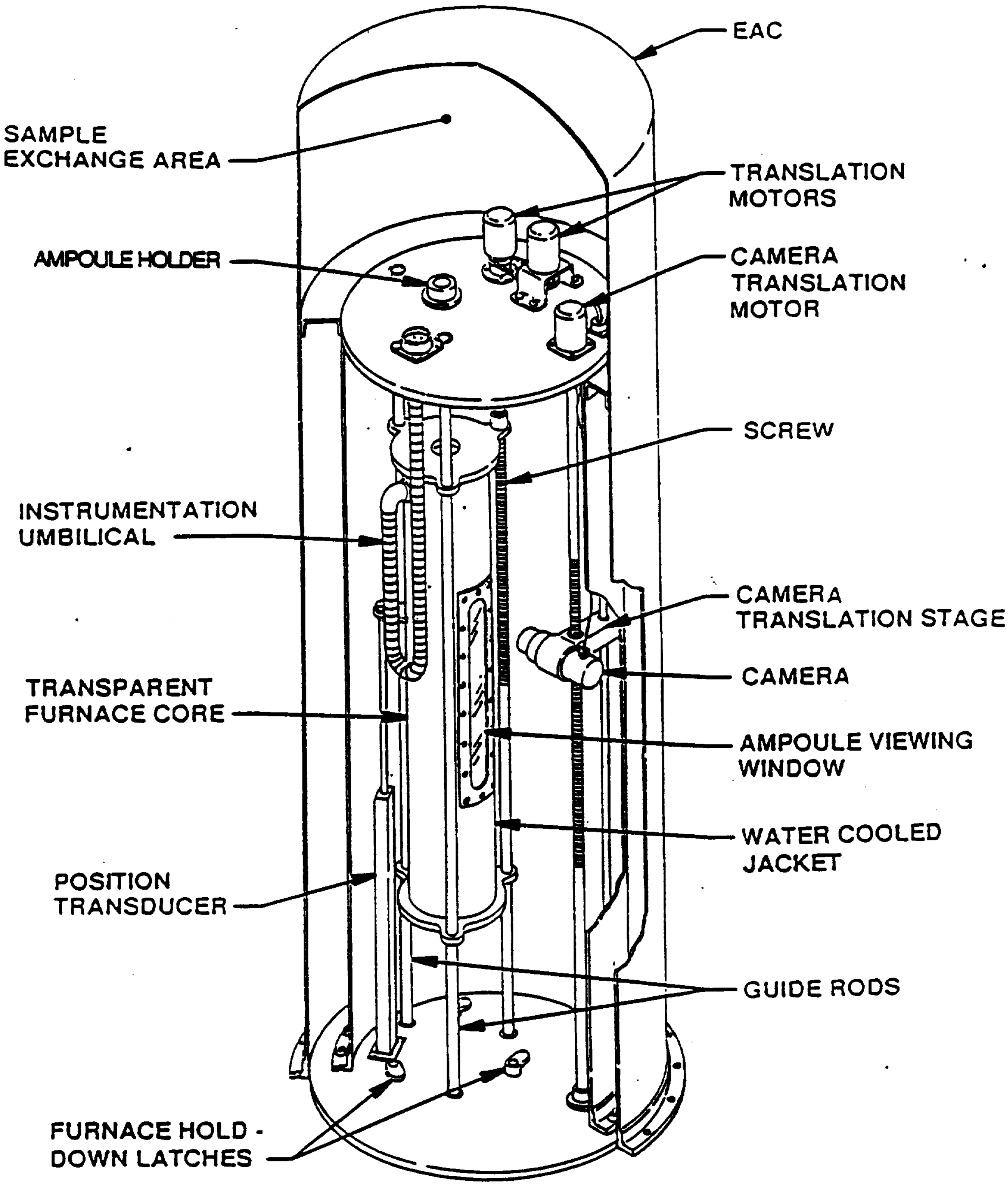


FIGURE 2.1-8. TRANSPARENT FURNACE MODULE CONCEPT

translating furnace core or a second wall surrounding the furnace core translation envelope. The second and third options place severe limitations on viewing flexibility but eliminate the problem of isolating the camera from heat. The camera will require a translation system for axial positioning along the sample. The camera support will also need to be gimballed for tilt. In some low temperature systems, a light may be needed for illumination of the solid-liquid interface.

2.1.4.5 Furnace Geometry - The translating heater zone configuration may require the furnace to translate up to approximately 1.5 times the usable sample length depending on the thermal gradient established by the heater zones and the experimental parameters. If the usable sample length is 15 in., at least 20 in. is required between the translation stops. It is estimated that the entire furnace module assembly will be 55 in. high and 18 in. in diameter. A conceptual design for the furnace module is shown in Figure 2.1-8.

2.1.4.6 Temperature Measurement - Three thermocouples, spaced in 120-deg radial increments, will be required for each zone. An 8-zone furnace will therefore require 24 thermocouples. It is estimated that an additional 20 thermocouples will be required for sample instrumentation and various other furnace temperature measurements raising the total thermocouple count to 80. A setpoint stability of ±0.5 °C is desired for temperature control. The required setpoint resolution is 0.1 °C. RTDs will be required to achieve this degree of resolution. Two RTDs will be used for measurement of the furnace module interior temperature. A non-contact temperature measurement system for direct solid-liquid interface temperature measurement is desirable but is a technology development issue. Absorption by the quartz ampoule limits current optical pyrometers. Optical pyrometry is not specified in the CRD.

Table 2.1-9 lists the resource requirements for the Visibly Transparent Furnace, while Table 2.1-10 shows sensor and control requirements.

2.1.5 Metals and Alloys Solidification Apparatus

The MASA is a Bridgman-type furnace which provides the capability for controlled directional solidification experiments on metals, alloys, and composites in the microgravity environment. The furnace system employs a

TABLE 2.1-9. RESOURCE REQUIREMENTS

Power	1500 W at 28 Vdc
Instrumentation voltage	TBD
Thermal Cooling Load	1500 W (90% liquid, 10% air)
Consumables	Argon will be required for backfill, approximately 150 liters/run
Vacuum	The furnace will need to be evacuated after each run, assuming that the furnace module does not incorporate a multiple sample exchange system.
Video	Approximately 512 x 512 pixel density at 1 frame per second in color
Process Times	Up to 10 days, processing + controlled cooldown

TABLE 2.1-10. TRANSPARENT FURNACE SENSOR AND CONTROL REQUIREMENTS (Sheet 1 of 3)

Heater Control

- 8 zones, 8 heaters, 8 heater drivers
- Up to 200 W per zone
- 800 °C maximum temperature
- ±.1 °C setpoint stability

Thermocouple Placement

- Thermocouples, spaced 120 deg apart, 1 set of three per zone - 24 thermocouples in the furnace core
- 2 thermocouples located in the sample ampoule
- Drive motor thermocouples, 4 motors, 1 thermocouple per motor, 4 thermocouples total
- Coolant loop thermocouples, 6 total
- "Structural" temperatures sensors, 1 on each heater core end cap, 3 on cooling jacket, 4 thermocuples total
- 2 camera temperature thermocouples
- 42 thermocouples total

Two Humidity Sensors

Position Measurement

- 1 linear potentiometer-furnace position
- 2 optical encoders
- 1 rotary potentiometer-camera position
- 1 micron furnace position measurement resolution

RTD

- 2 furnace atmosphere temperature sensors
- 2 coolant water temperature sensors
- 1 RTD/zone; 8 in furnace core

TABLE 2.1-10. TRANSPARENT FURNACE SENSOR AND CONTROL REQUIREMENTS (Sheet 2 of 3)

Limit Switches

- 2 on furnace core translation system
- 1 on furnace core latch-down system
- 2 on furnace camera translation system
- 1 on camera latch-down system
- "Ampoule in place" verification sensor

Pressure Sensors

- 2 sensors for coolant pressure drop
- 1 vacuum gauge
- 1 backfill gas pressure sensor

Solenoid Valves

- 1 valve on coolant supply
- 1 valve on coolant return
- 1 valve on vacuum line
- 1 valve on backfill gas supply
- Verification sensors on all valves

Video Requirements

- Standard TV frame rate and pixel density is acceptable

TOTAL NUMBER OF SENSORS:

42 thermocouples
2 humidity sensors
12 RTDs
6 limit switches
4 fluid pressure sensors - analog output
2 ampoule failure detection sensors - resistance measurement
10 current and voltage sensors on heater drivers
5 verification sensors - discrete outputs
2 potentiometer position sensors
2 optical encoder position sensors

TABLE 2.1-10. TRANSPARENT FURNACE SENSOR AND CONTROL REQUIREMENTS (Sheet 3 of 3)

Outputs:

8 heater drivers

4 solenoid valves

2 motor controls for driving 2 steppers in microstepping mode - 4 phase

1 dc motor control for rapid translation motor

1 failsafe brake

2 hold-down solenoids

2 standard brakes

Rates

- 10-Hz sampling on thermocouples and RTDs
- 1-Hz video frame rate

Total Inputs and Outputs

- Analog 3 at 1 Hz
  78 at 10 Hz
- Discrete 15 at 10 Hz
  5 at 1 Hz
- Special 2 at 10 Hz
  2 at 20 Hz

"rapid quench" capability which provides a 100 °C quench rate in 1-cm diameter samples. The furnace system has a maximum temperature capability of 1600 °C.

The objective of the MASA is to maximize sample throughput since the solidification rates required for metals and alloys experiments are often of the order of centimeters or millimeters per minute.

The MASA module consists of a furnace with a hot zone, an adiabatic layer, and a cold zone. A negative pressure difference between the canister and the lab environment can be maintained. The furnace has a 3-cm bore. The hot zone has a length of 18 cm and its temperature can be varied from 300 °C to 1600 °C. There are three independently controlled heaters in the hot zone including a 1700 °C booster heater.

A 5-cm long quench zone is adjacent to the cold zone. The quench zone facilitates a 100 °C per second quench rate in 1-cm diameter samples. Configured for Spacelab, the system contains a 2800 cm^3 water supply which is filled before each run. The quench water is driven from the tank by expansion of an internal bladder caused by argon pressure.

Sample diameters are variable up to 2 cm. For safety within the lab, the samples are contained in sealed sample canisters. Steep thermal gradients can be achieved with 1-cm diameter samples during directional solidification. During directional solidification and quench, the MASA uses furnace translation rather than sample translation to minimize induced accelerations to the sample. A schematic of the complete MASA system within a U. S. standard equipment rack is shown in Figure 2.1-9.

Furnace translation rate is variable from 0.36 mm/h to 3,600 mm/h. The translation system distance of travel is sufficient to allow for insertion and removal of the sample and position it in the hot zone center. The apparatus includes a mechanism for automated sample oscillation during hot soak.

The furnace is installed within an environmental canister for containment of toxic vapors.

The MASA module configured for the Spacelab is controlled by a Dedicated Experiment Processor (DEP) which serves as the electric/electronic interface with the Spacelab CDAS. Power is delivered to the DEP from the rack

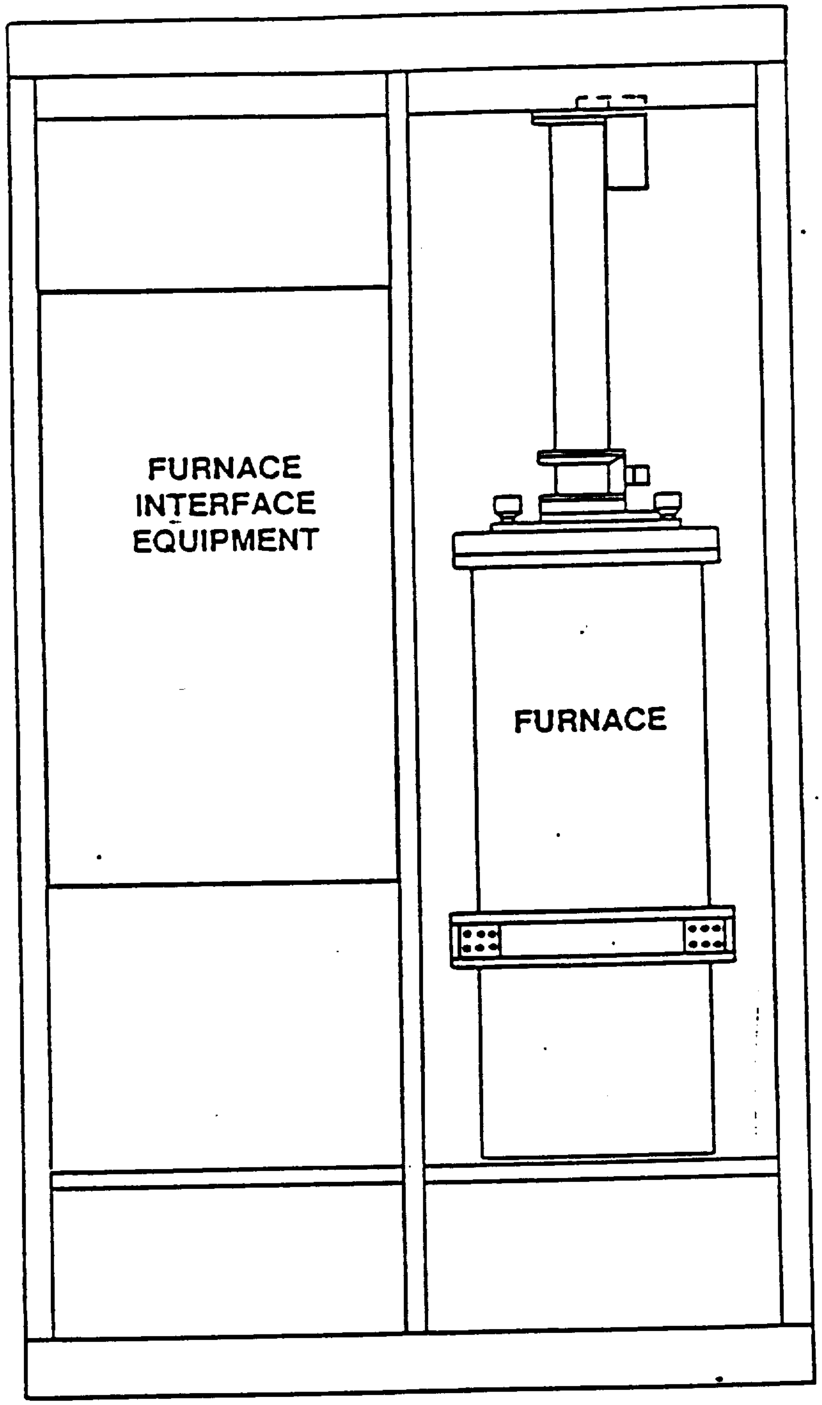


FIGURE 2.1-9. MASA RACK LAYOUT

EPSP. The DEP may be programmed to respond to commands from the Experiment Computer (EC) and provide power to the operating subsystems and equipment.

Program instructions to the DEP may be entered through the Spacelab experiment computer keyboard and transmitted via the experiment Remote Acquisition Unit (RAU) to the DEP. Uplink command data is also transferred through the experiment RAU to the DEP. Experiment output data is offloaded to the Spacelab High Rate Multiplexer (HRM) where it is passed on to the High Data Rate Recorder (HDRR) or downlinked to the ground. These interfaces are shown in Figure 2.1-10.

The functions of the EC, RAU, HDRR, HRM, and EPSP will be provided by the SSFF Core Facility. The functions of the DEP will be split between the MASA module electronics and the SSFF Core Facility.

The resource requirements for MASA, as shown in Table 2.1-11, were derived from the most recent available data on the system.

2.1.6 Magnetic Suppression System Concepts

In the processing of metals, oxides, glasses, and electronic materials, the reduced gravity of space offers the opportunity to produce materials with unique or improved properties. This is especially true in crystal growth because the reduction of gravity-driven flows could potentially result in higher quality crystals which can be used in electronic devices to enhance their performance. It is desired to ultimately produce commercial scale samples which may range up to 10 cm in diameter. For samples this size, it is expected that the effects of gravity-driven convection will be significant even in the reduced gravity environment in space. For this reason, it is desired to further reduce the effects of gravity through the use of magnetic suppression, which involves performing the sample processing in the presence of a magnetic field in a direction parallel to the solidification axis of the sample.

The approach to performing this study involves a consideration of different types of magnet systems which have been classified into three categories: (1) superconducting magnet systems, (2) normal electromagnet systems, and (3) permanent magnet systems. Concepts from each category are discussed in the following paragraphs.

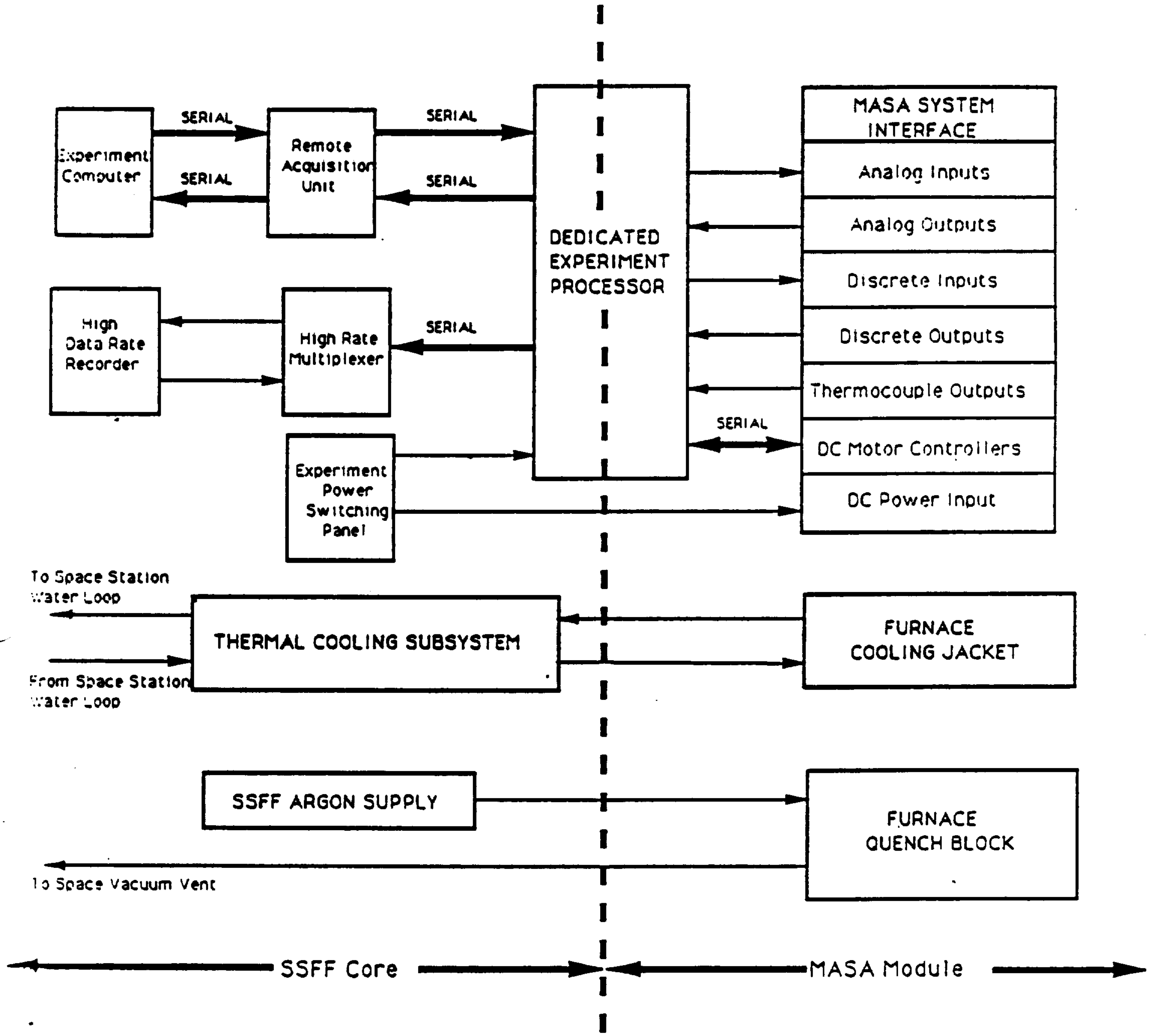


FIGURE 2.1-10. MASA/SSFF CORE INTERFACE DEFINITION

TABLE 2.1-11. RESOURCE REQUIREMENTS

Physical Properties	The mass properties of the equipment in the MASA are given in Table 2.1-12. The furnace module and necessary electronics and interface equipment are expected to fit into a U.S. standard equipment rack.
Power	The maximum power required for the MASA furnace is 1200 W. The average power is 800 W during an experiment operating cycle. The MASA is designed to use 28 Vdc.
Thermal Requirements	Heat is dissipated from the furnace into the module liquid coolant loop. The liquid coolant loop is also required to control the temperature in the furnace cold block via a water/water heat exchanger. The heat rejection from the sample to the cold block is nominally 350 W while the furnace is being operated. The furnace canister water jacket requires coolant from the module coolant loop also. The peak heat removal capability required from the avionics loop is approximately 400 W.
Waste Fluids and Gases	The quench operation uses an SSFF Core provided source of quench water. The quench operation requires nominally 280 cm^3 for 14 sec during each quench. The quench supply pressure requirement ranges from 15-50 psi. Waste argon gas released by the furnace canister during pressure relief will be routed to the SSFF Fluids Distribution System .
Data	The Input/Output (I/O) channel definition for the MASA is shown in Table 2.1-13. The control systems monitored and controlled by the SSFF Core and the anticipated data rates required for furnace operation are shown in Tables 2.1-14, 2.1-15, 2.1-16, and 2.1-17. The total number of channels is 58, the average sampling rate is 20 samples/sec, and the average data rate is 650 kb/sec. The translation motor drive is expected to have a data rate of 40,000 samples/sec.

TABLE 2.1-12. MASA EQUIPMENT MASS PROPERTIES

EQUIPMENT ITEM	MASS (kg) (Estimated)
MASA Apparatus	100
Support Frame	30
Sample Canister Stowage	TBD
TOTAL	130+

TABLE 2.1-13. MASA I/O CHANNEL DEFINITION

ITEM	IDENTIFICATION	RANGE
1	Analog Inputs	0-5 Vdc
2	Analog Outputs	0-2.5 Vdc
3	Discrete Inputs	28 Vdc
4	Discrete Outputs	28 Vdc
5	TTL Inputs (Encoder)	5 Vdc
6	Type-B Thermocouples Inputs	≤1700 °C
7	Type-K Thermocouples	≤200 °C
8	RS-232 I/O	N/A

TABLE 2.1-14. MASA MOTOR CONTROL MONITORS

ITEM	IDENTIFICATION	IDENTIFICATION	QTY
1	Brushless dc Motor	Furnace Translation	2
2	Brushless dc Motor	Sample Insertion	1
3	dc Motor Controller(s)	Control of dc Motors	3
4	Optical Encoder	Furnace Position Indication	1
5	Limit Switch	Sample-in-Place Indication	1
6	Limit Switch	Furnace Home, Extreme Travel Indication	2

TABLE 2.1-15. MASA THERMAL CONTROL SYSTEM DATA REQUIREMENTS

ITEM	IDENTIFICATION	QTY	SAMPLES/sec
1	Booster Heater T/C	2	1-40
2	Main Heater T/C	2	1-40
3	Trim Heater T/C	2	1-40
4	Sample T/C	6	1-40
5	Current Sensor	3	1-40
6	Chamber T/C	1	1
7	Argon Atmosphere T/C	1	1

TABLE 2.1-16. MASA WATER LOOP BLOCK DATA REQUIREMENTS

ITEM	IDENTIFICATION	SAMPLES/sec
1	Cooling Water Inlet Flow Meter	1
2	Cold Block Water Inlet Flow Meter	1
3	Cold Block Water Outlet Flow Meter	1
4	Cold Block Pump	N/A
5	Cold Block Heat Exchanger	N/A
6	Cooling Water Inlet Check Valve	1
7	Cooling Water Inlet T/C	1
8	Water Jacket Outlet T/C	1
9	Heat Exchanger Outlet T/C	1
10	Cold Block Water Inlet T/C	1
11	Cold Block Water Outlet T/C	1

TABLE 2.1-17. MASA ENVIRONMENTAL BLOCK DATA REQUIREMENTS

ITEM	IDENTIFICATION	SAMPLES/sec
1	Argon Supply Pressure Transducer	20
2	Chamber Argon Pressure Regulator for Inlet	N/A
3	Chamber Argon Pressure Regulator for Outlet	N/A
4	Enable Chamber Argon in Valve	N/A
5	Chamber Pressure Transducer	20
6	Quench Water Supply Pressure Regulator	N/A
7	Enable Quench Water Valve	N/A
8	Argon Supply Shutoff Valve	N/A
9	Enable Quench Control Line Valve	N/A
10	Quench Exhaust Line Relief Valve	N/A
11	Enable Quench Exhaust to Vent Line	N/A
12	Enable Vacuum Vent Valve	N/A
13	Quench Water Inlet T/C	20
14	Furnace Canister Argon T/C	20
15	Furnace Canister Surface T/C	20
16	Quench Inlet Water Pressure	20

Magnetic Field Shield Design

Because of the requirements limiting magnetic field emissions from payloads on the SSF, it is necessary to use a magnetic field shield in conjunction with the magnet in the magnetic suppression concept since the magnitude of the flux desired (2,000 gausses) is far greater that the anticipated limiting value on emissions. For dc fields, a magnetic field shield provides a low-reluctance path for the magnetic flux being shielded. The attenuation or shielding efficiency of a magnetic shield is the ratio of the measured field before shielding to that measured after shielding. In general, magnetic shields that are cylindrical provide greater attenuation than shapes with square corners. For cylindrical shields, the attenuation is inversely proportional to the inside diameter of the shield, thus the larger the volume of the shielding chamber the lower its attenuation for a given thickness of shielding material.

In magnetic field shield construction, it is desirable to select a material with a high permeability for high attenuation and a high saturation level. Above saturation, shielding effectiveness drops exponentially. A typical material used in the construction of magnetic field shields is mu-metal. Mu-metal is an alloy of nickel, copper, chromium, and iron. It has a maximum permeability of 100,000 and a saturation induction of 6,500 gausses. In this study, mu-metal is considered for the magnetic field shield construction as well as two alloys which are commercially available and will be referred to here as "Alloy 1" and "Alloy 2." The properties of interest of these alloys are presented in Table 2.1-18. "Alloy 1" has a very high permeability for maximum attenuation, but a low saturation level. "Alloy 2" has a relatively low permeability, but a high saturation level. The B/H curves for the three magnetic shielding materials considered in this study are presented in Figures 2.1-11, 2.1-12, and 2.1-13.

Using the given properties and B/H curves, the performance of each material was evaluated in this study. Figure 2.1-14 shows a plot of the level of magnetic flux emitted by a magnetic shield as a function of the shield thickness for the three alloys under consideration. The magnetic flux emitted by the shield is the flux level after shielding. This plot was produced for an interference field of 2,000 gausses and a shield inside diameter of 44 cm. From this plot, at an emitted flux level of 0.3 gauss, "Alloy 1" requires the smallest shield thickness, which is mainly because it has the highest permeability. "Alloy 1" is selected

TABLE 2.1-18. MAGNETIC FIELD SHIELD MATERIAL PROPERTIES

	Mu-Metal	"Alloy 1"	"Alloy 2"
Specific Gravity	8.5	8.74	7.86
Saturation Induction, Gauss	6,500	7,500	21,000
Maximum Permeability	100,000	450,000	4,000
Coercive Force, Oe	0.05	0.015	1.0
Curie Temperature, °C	400	454	770

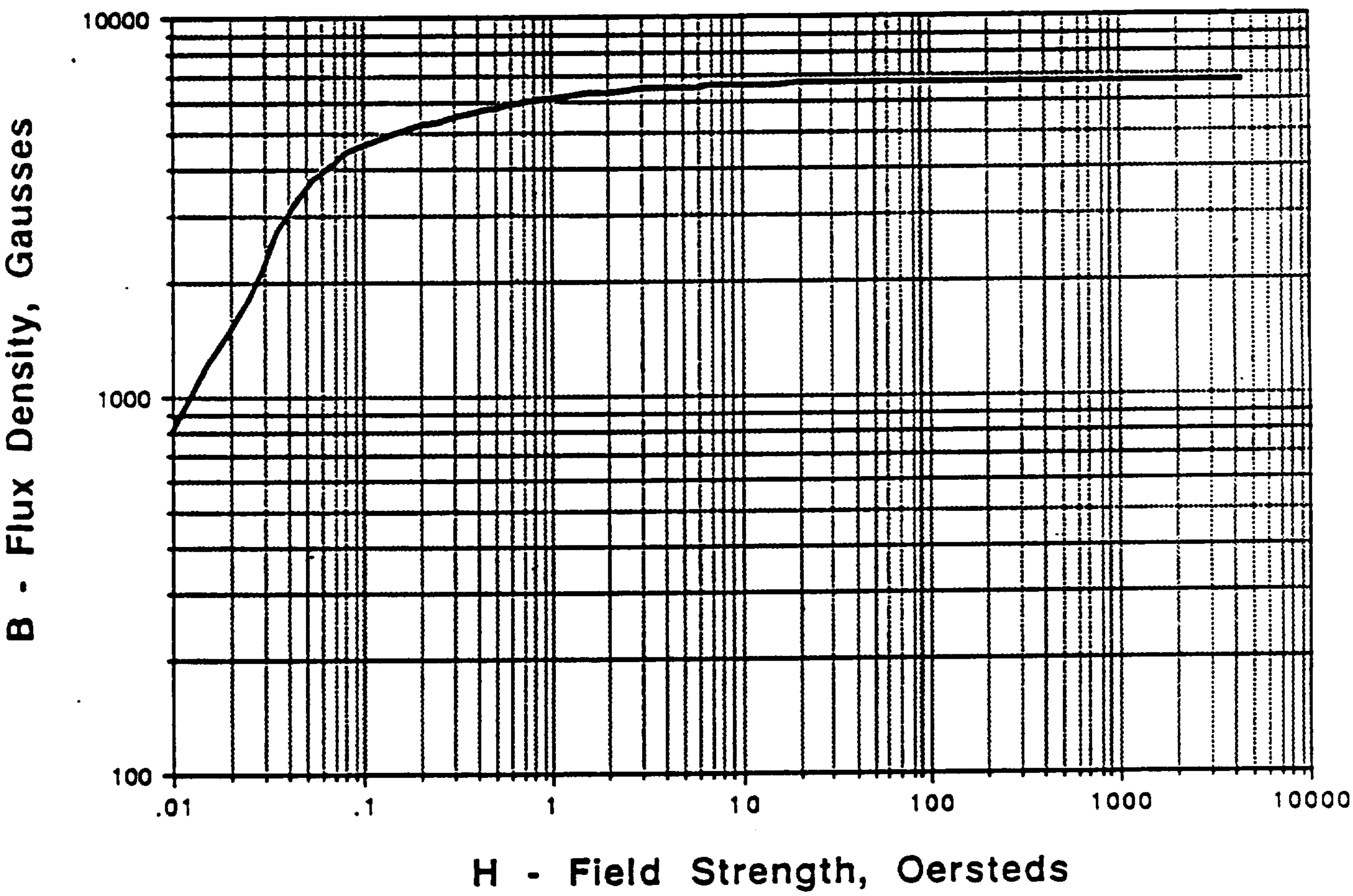


FIGURE 2.1-11. B/H CURVE FOR MU-METAL

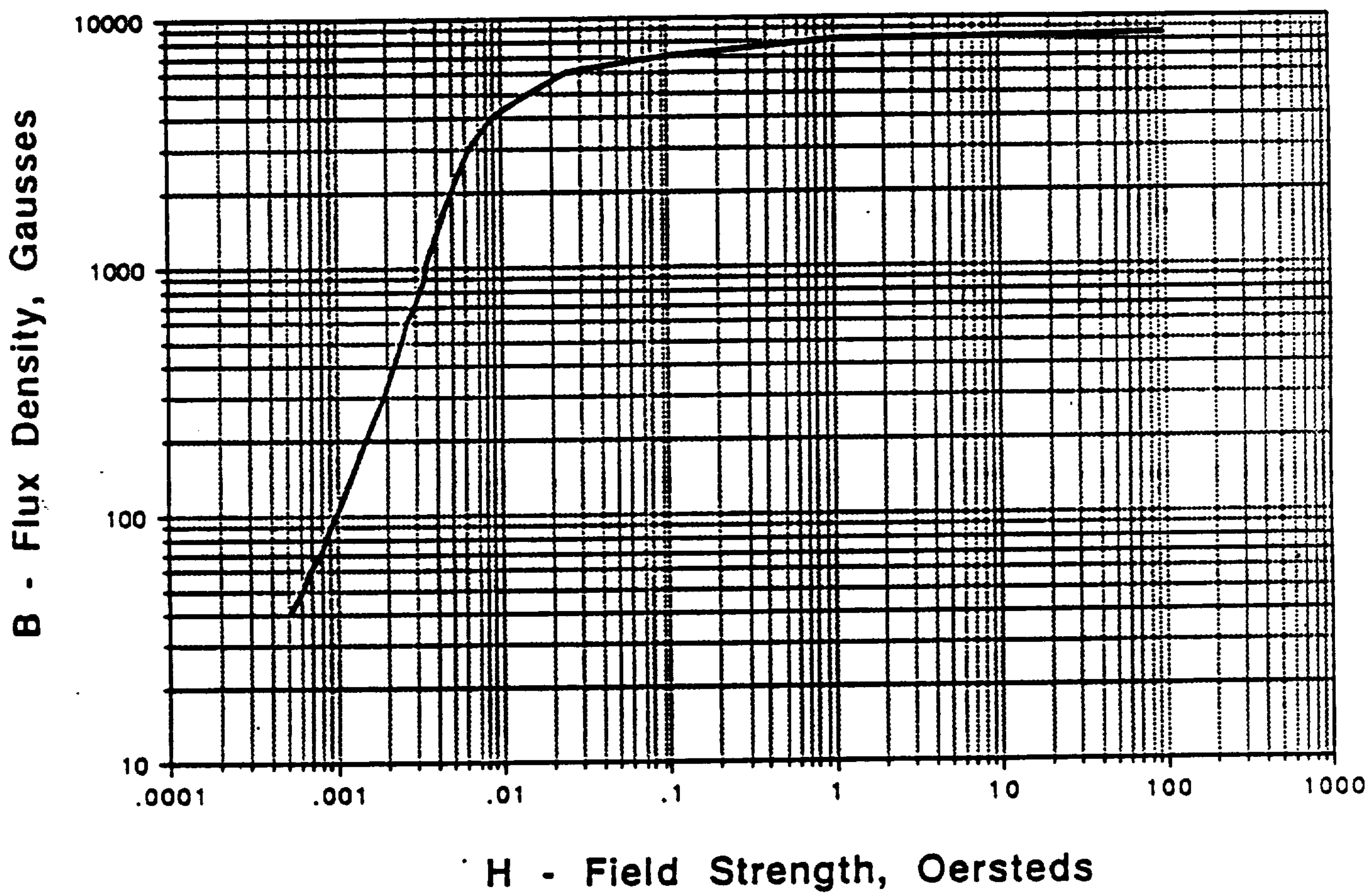


FIGURE 2.1-12. B/H CURVE FOR "ALLOY 1"

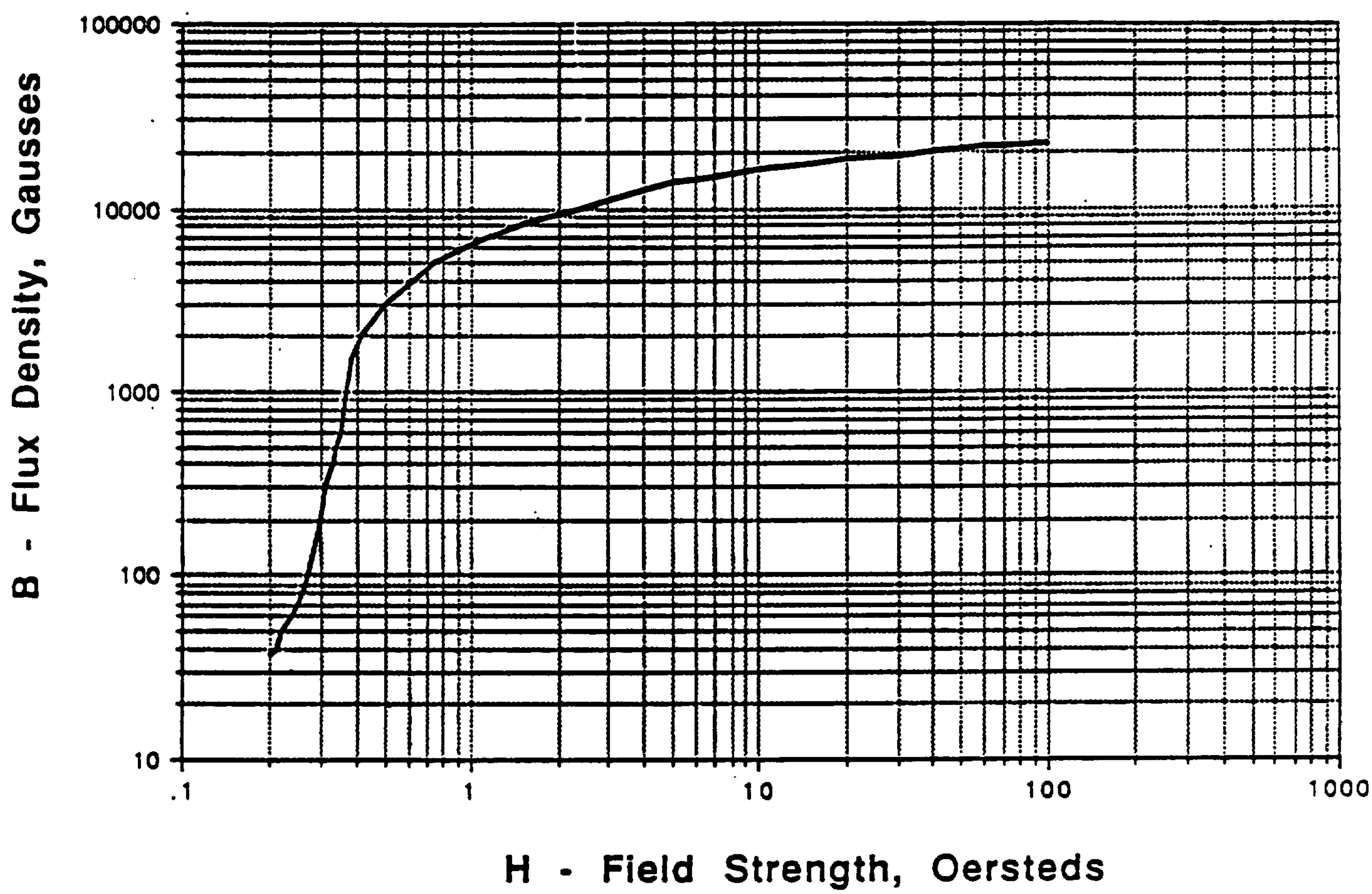


FIGURE 2.1-13. B/H CURVE FOR "ALLOY 2"

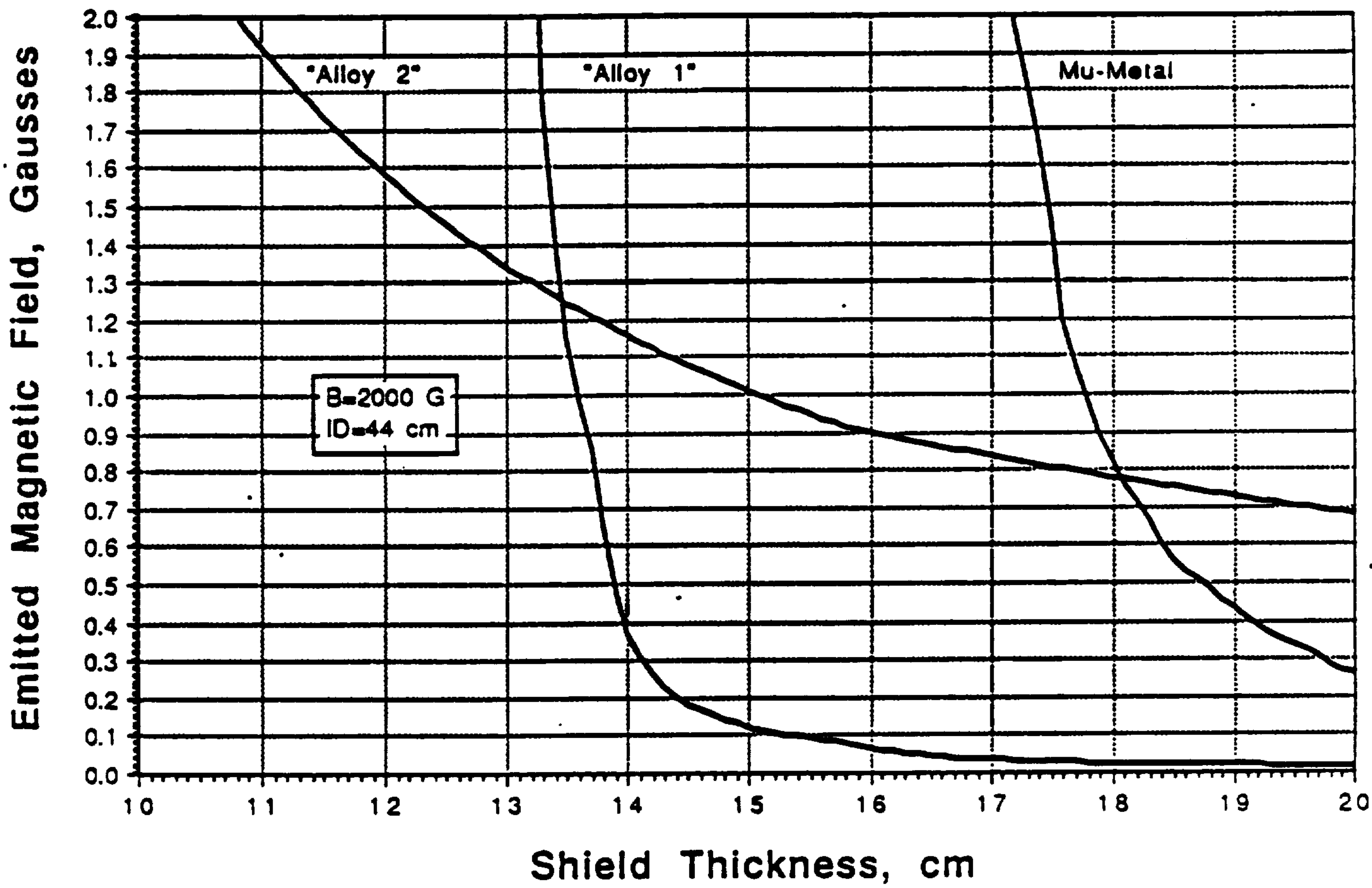


FIGURE 2.1-14. PLOT OF EMITTED MAGNETIC FIELD VS SHIELD THICKNESS FOR SHIELD MATERIALS

here as the material for the shield construction, and, for this alloy, the level of magnetic flux after shielding is plotted as a function of shield thickness for various shield inside diameters in Figure 2.1-15. This plot was developed for an interference field of 2,000 gausses. Thus, this figure can be used to determine the required shield thickness for various shield sizes. Figure 2.1-16 is a plot of the resulting shield mass versus the shield thickness for various shield inside diameters. This plot was developed for an interference field of 2,000 gausses also. Figure 2.1-17 is a plot of the minimum shield thickness required to avoid material saturation as a function of the shield inside diameter for various source or interference flux values.

Superconducting Magnet System Concept

The superconducting magnet concept consists of three major assemblies: the magnet and dewar, a closed-cycle refrigerator, and a power supply and control system.

The dewar has a clearance bore to permit the insertion of a crystal growing furnace module in its center. The dewar is equipped with fixtures to allow liquid helium and liquid nitrogen filling and venting. The dewar is also plumbed to allow connections to the closed-cycle refrigerator. The magnet resides in a helium-filled chamber which is maintained at 4.2 °K. To minimize helium consumption, the magnet chamber is surrounded by a radiation shield which is stored in liquid nitrogen and maintained at 20 °K. The outer surface of the dewar is maintained at room temperature. The dewar is instrumented with temperature sensors attached to the radiation shields and the magnet chamber. The U.S. standard SSF rack will not accommodate the dewar; therefore, nonrack provisions must be made for it.

The magnet is a solenoid, typically wound using conductors made of many filaments of superconductor embedded in a copper matrix and twisted along its axis to decrease its diamagnetism. Insulation is provided by the insulation on the wire and by epoxy between each turn. The magnet is wound on a cylinder made of aluminum, brass, or stainless steel.

The closed-cycle refrigerator is used to maintain the radiation shields at 20 °K. It is attached to the top of the dewar by an armored cable. Terrestrial refrigerators are air-cooled. The refrigerator can be installed in a U.S. standard SSF rack.

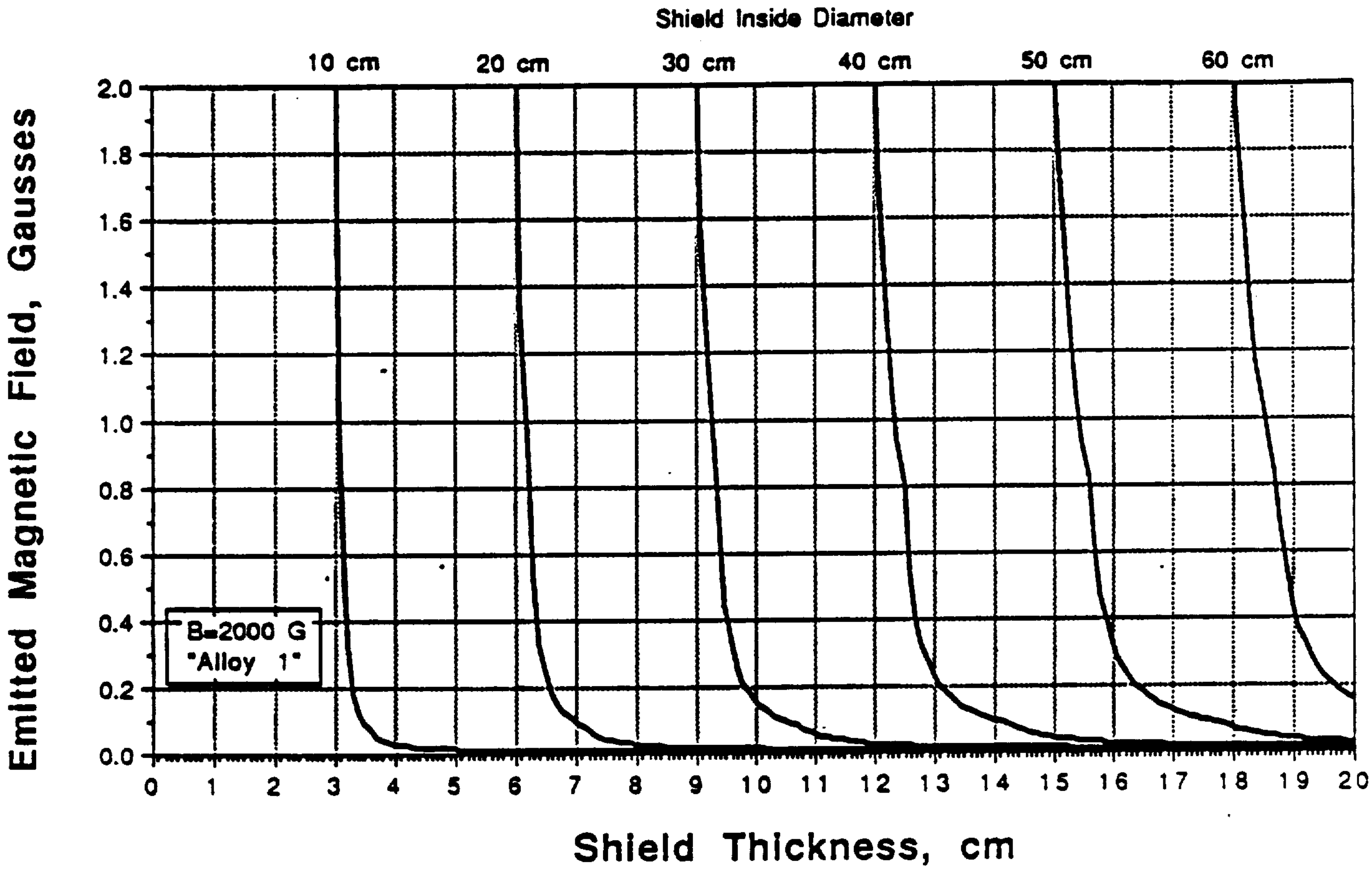


FIGURE 2.1-15. PLOT OF EMITTED MAGNETIC FIELD VS SHIELD THICKNESS ("ALLOY 1")

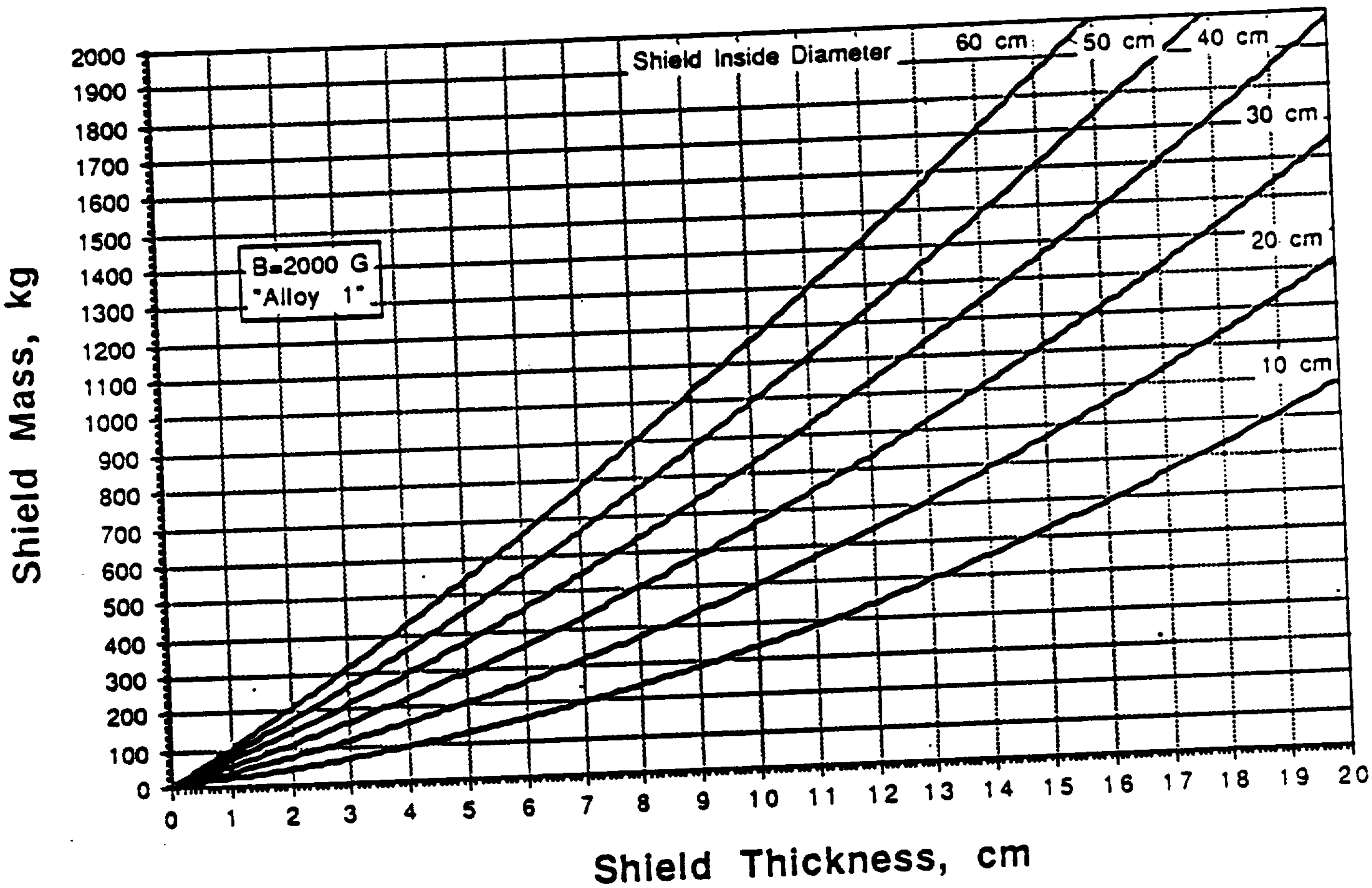


FIGURE 2.1-16. PLOT OF SHIELD MASS VS SHIELD THICKNESS ("ALLOY 1")

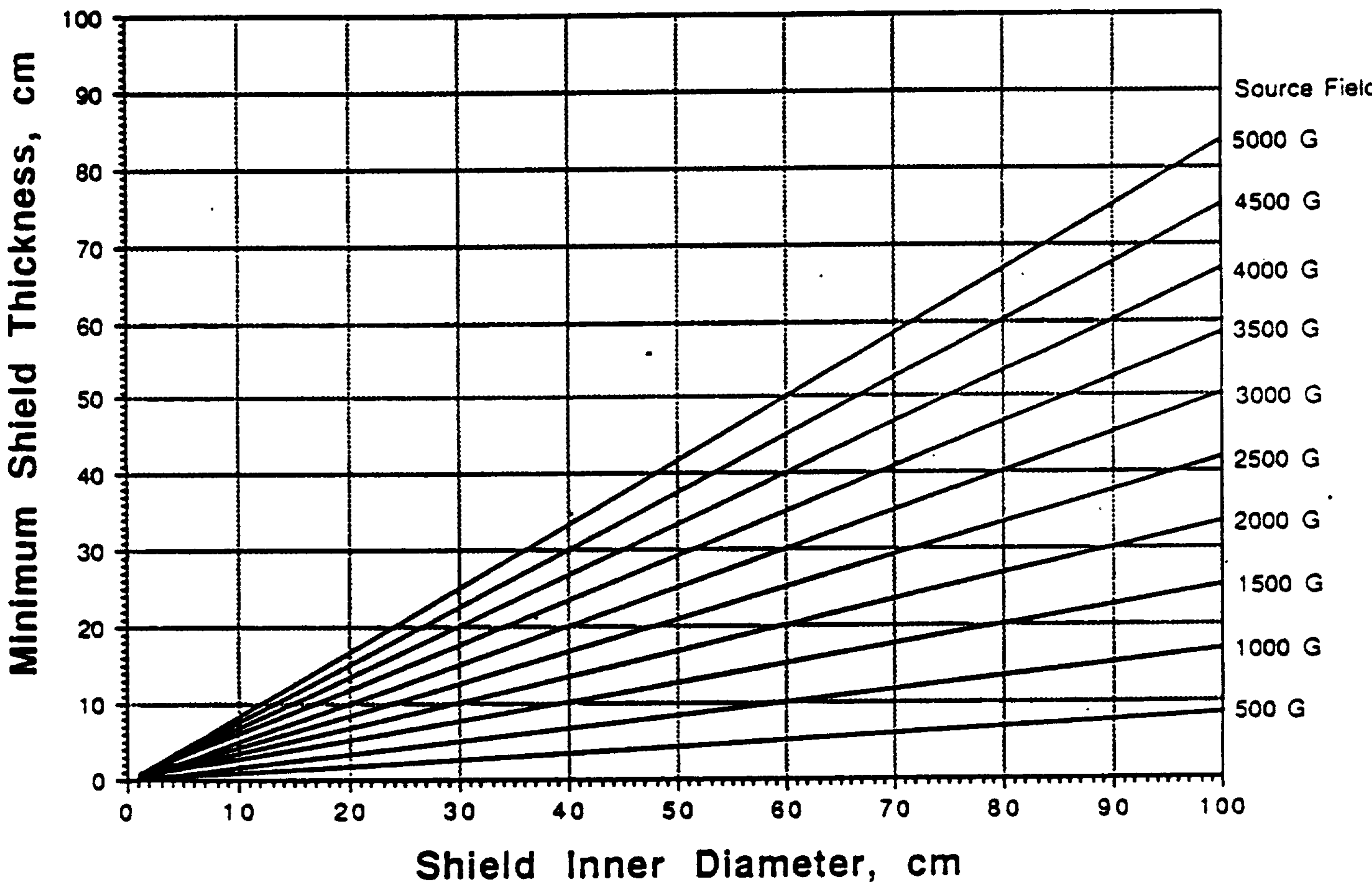


FIGURE 2.1-17. PLOT OF MINIMUM SHIELD THICKNESS VS INNER DIAMETER ("ALLOY 1")

The magnet controls and instrumentation and power supplies can be installed into a standard U.S. rack.

The resource requirements presented in Table 2.1-19 are based on an actual terrestrial state-of-the-art superconducting magnet system using a 5 K Gauss magnet. This system is manufactured by a leading supplier of superconducting magnet systems and cryogenic accessories.

Permanent Magnet System Concept

Concepts for using a permanent magnet have been examined in this study. From literature on the subject and discussions with manufacturers of permanent magnets, it was concluded that the only way that a permanent magnet could be used in this application is by placing the magnet in a magnetic circuit. To use a permanent magnet alone with no circuit, to produce a 2,000-gauss magnetic field at the required distance from the magnet surface, would require a very massive magnet, and it did not appear to be a viable option. In this concept, the magnetic circuit considered is shown in Figure 2.1-18. In this circuit, the magnet has a rectangular cross-section, and pole pieces of mild steel are used to direct the flux to the working gap where the furnace module is placed. The length of the gap must be sufficient to accommodate the overall length of the furnace module. In this concept, a furnace module with an outside diameter of 20 cm and an overall length of 50 cm is considered.

Even though permanent magnets seem physically simple, their operational complexities are evident when the factors that affect the performance of magnets are considered. There are few sources of practical, published information to provide the necessary expertise in magnetics. Some of the factors that affect the performance of permanent magnets are: the magnet material, size, and shape; location of the magnet in the circuit; level of magnetization; location of the poles; magnetization before or after placement in the circuit; material of which poles are made; shape of the pole pieces; environmental conditions such as temperature, shock, and demagnetizing fields; the material making up the part on which the magnet acts; and the size of the part on which the magnet acts.

TABLE 2.1-19. RESOURCE REQUIREMENTS

Mass and Volume Requirements	The inner bore of the dewar is 86.36 cm in diameter and the outside diameter is 163.20 cm. This inner bore dimension is expected to be large enough to accommodate the furnace modules in the SSFF study and allow room for additional insulation around the furnace module if necessary to decrease nitrogen and helium consumption by the magnet system. The dewar and magnet weigh 6,000 lb. The closed-cycle refrigerator is expected to fit into a standard rack and weighs 140 lb. The power supply and control system will weigh 298 lb.
Power Requirements	The magnet must be energized before operation. The electrical power to energize the magnet is 1.6 kW, and the time to energize the magnet is 30 min. After the magnet is energized, it can be switched to a persistent mode where there is no power requirement. The closed-cycle refrigerator requires 1.5 kW continuously. It is estimated that the power supply and control system will consume about 500 W continuously.
Consumables	As heat is absorbed by the system, the liquid nitrogen and liquid helium in the system will vaporize and must be replaced periodically. The liquid nitrogen consumption rate is approximately 4 L/h and the liquid helium consumption rate is approximately 200 mL/h.
Venting	The helium and nitrogen gases from the magnet system must be vented if not captured and stored for reuse. Provisions must be made for rapid venting in the case of loss of cooling or some other catastrophic event since the magnet system will have a large amount of stored energy.

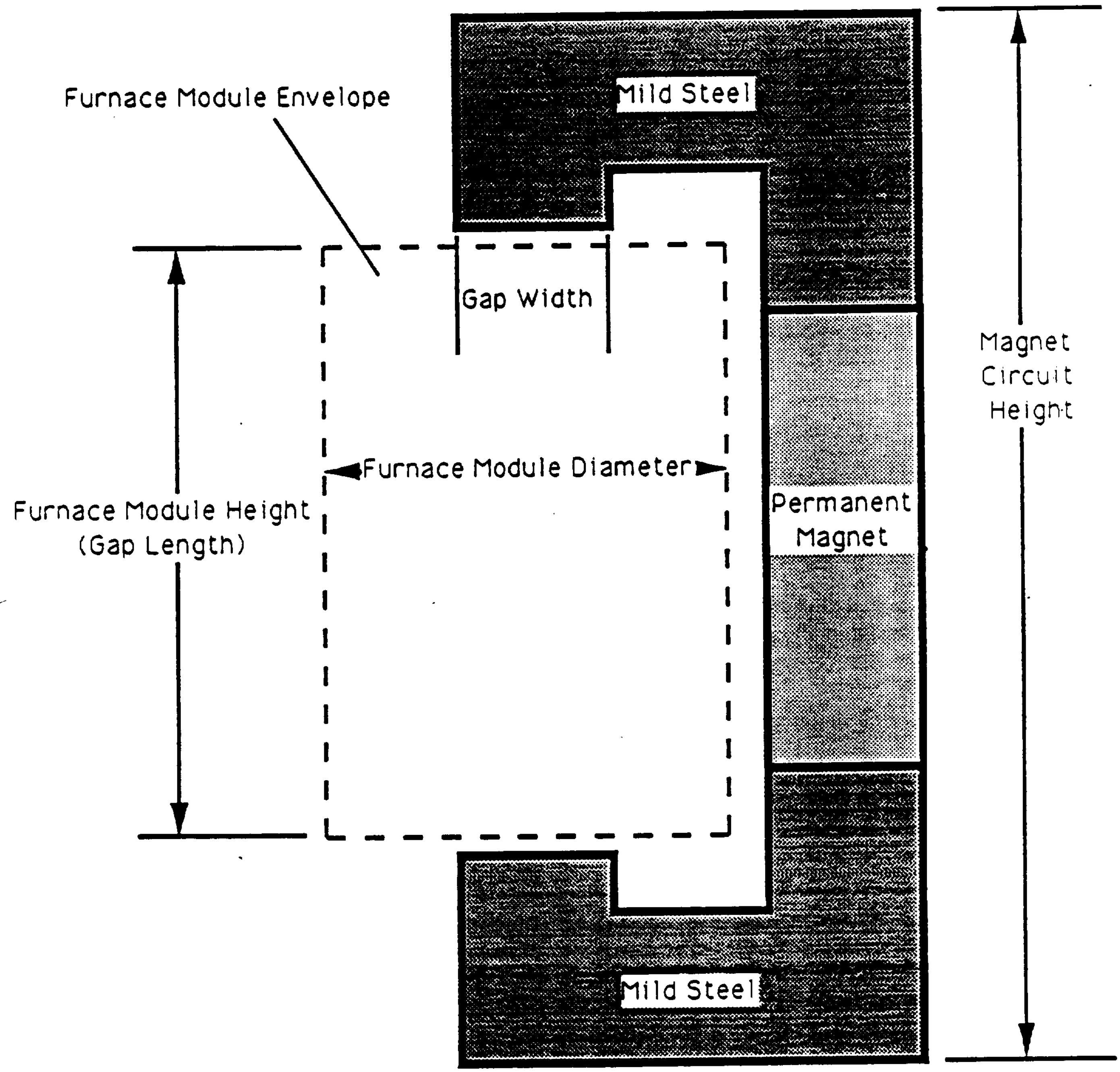


FIGURE 2.1-18. PERMANENT MAGNET CONCEPT

In this study, different magnet materials were considered and calculations were performed using Alnico V and a rare Earth magnet NdFe24. From the study of magnetics, it is evident that the B/H ratio is the key to how a basic magnet will perform in the circuit. The demagnètization/energy product curves for the magnet materials considered in this concept are shown in Figures 2.1-19 and 2.1-20.

When using a permanent magnet, consideration must be given to the flux that never reaches the air gap. The cross-sectional area of the magnet must be sufficiently sized to allow for flux losses. Flux lines will always follow the path of least reluctance and some flux will "jump across" the length of the magnet. This leakage flux must also be supplied by the magnet, and it requires an increase in area by some leakage factor. In practice, these factors range from 1.1 to 50. For this concept, the leakage factors were calculated and accounted for in determining the magnet size. In magnet design, the leakage fluxes can be reduced to two parts:

- The flux near the air gap that does not pass directly across the gap but runs parallel to it. This is called the fringing flux.
- The flux that radiates between the legs or across the back of all parts of the circuit. This is called the leakage flux.

The leakage factor can be based on permeance of the paths and can be expressed as the ratio of the total permeance and the permeance of the gap. A series of equations commonly used to estimate the permeances for various space considerations were used to calculate the permeances of the circuit in this concept.

In this study, it was felt that the mass and volume of the circuit would be the drivers of the feasibility of the use of a permanent magnet. For the magnetic circuit considered, the magnet length was varied and the resulting circuit mass, circuit height, circuit width, magnet thickness, and total permeance were calculated. These variables were plotted versus magnet length for both magnet materials considered for a flux of 2,000 gausses in the air gap. For Alnico V, Figure 2.1-21 is a plot of circuit mass versus magnet, Figure 2.1-22 is a plot of circuit length versus magnet length, Figure 2.1-23 is a plot of circuit width versus magnet length, Figure 2.1-24 is a plot of magnet thickness versus

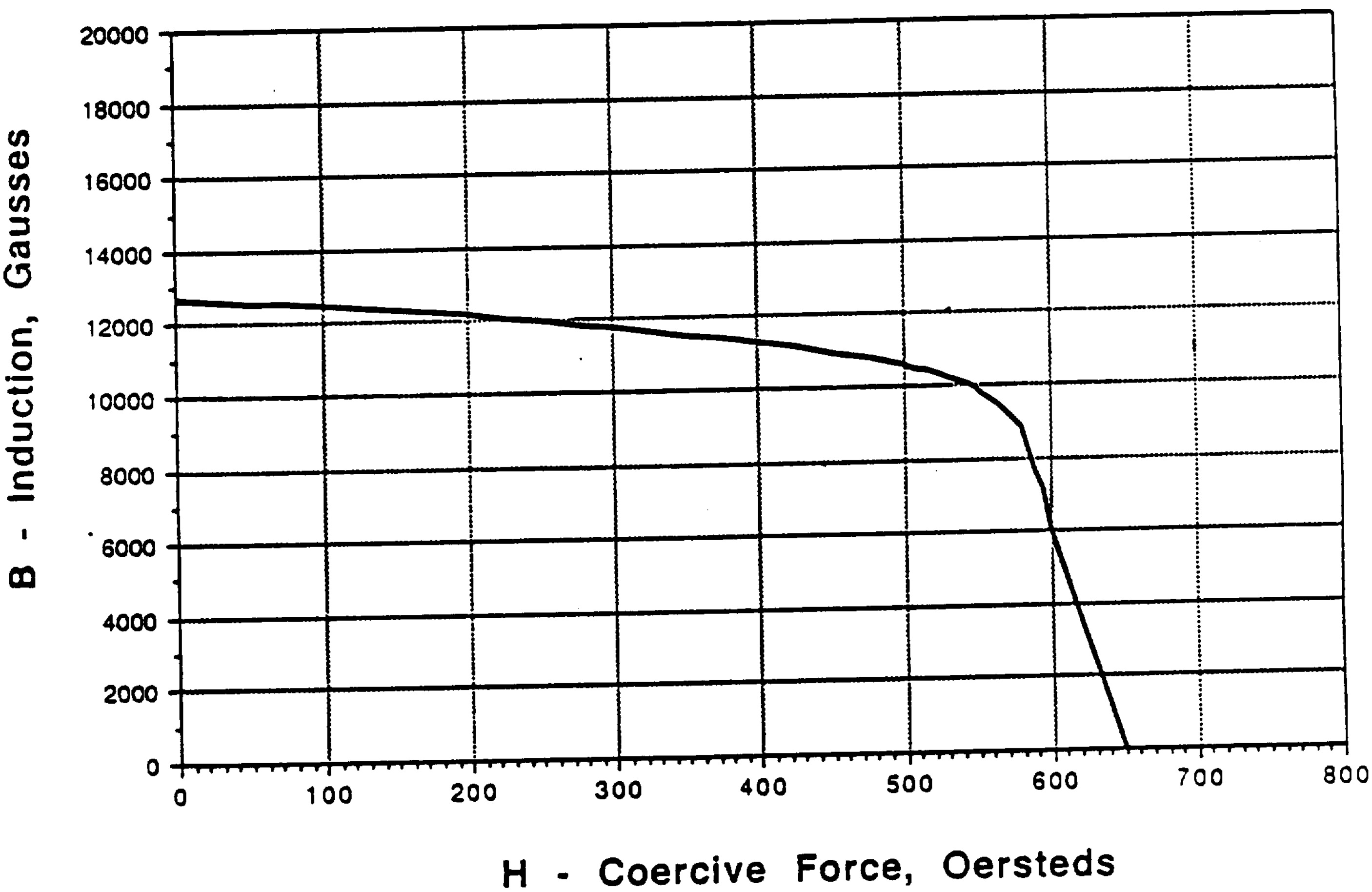


FIGURE 2.1-19. DEMAGNETIZATION CURVE FOR ALNICO V

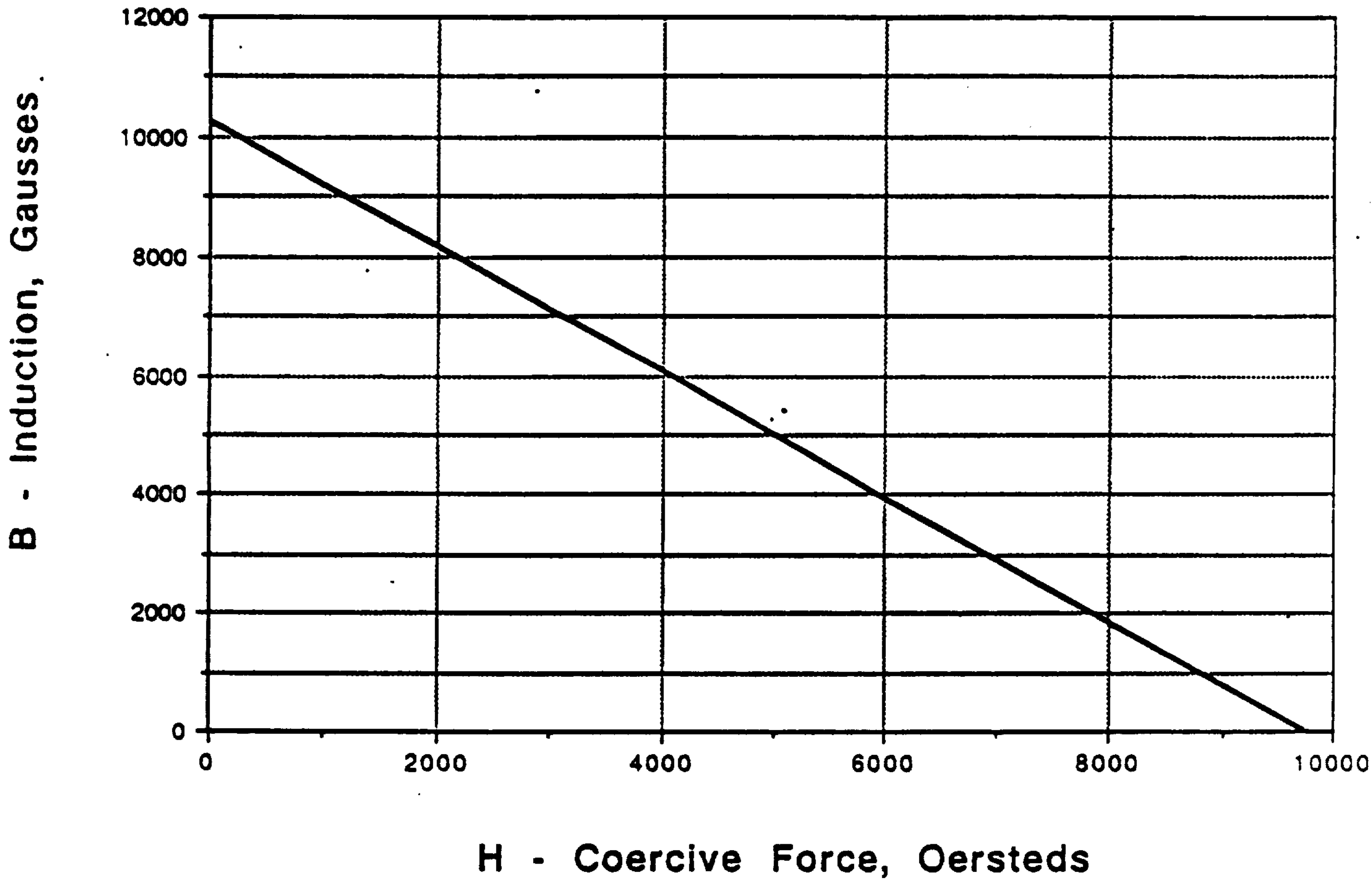


FIGURE 2.1-20. DEMAGNETIZATION CURVE FOR NdFe24

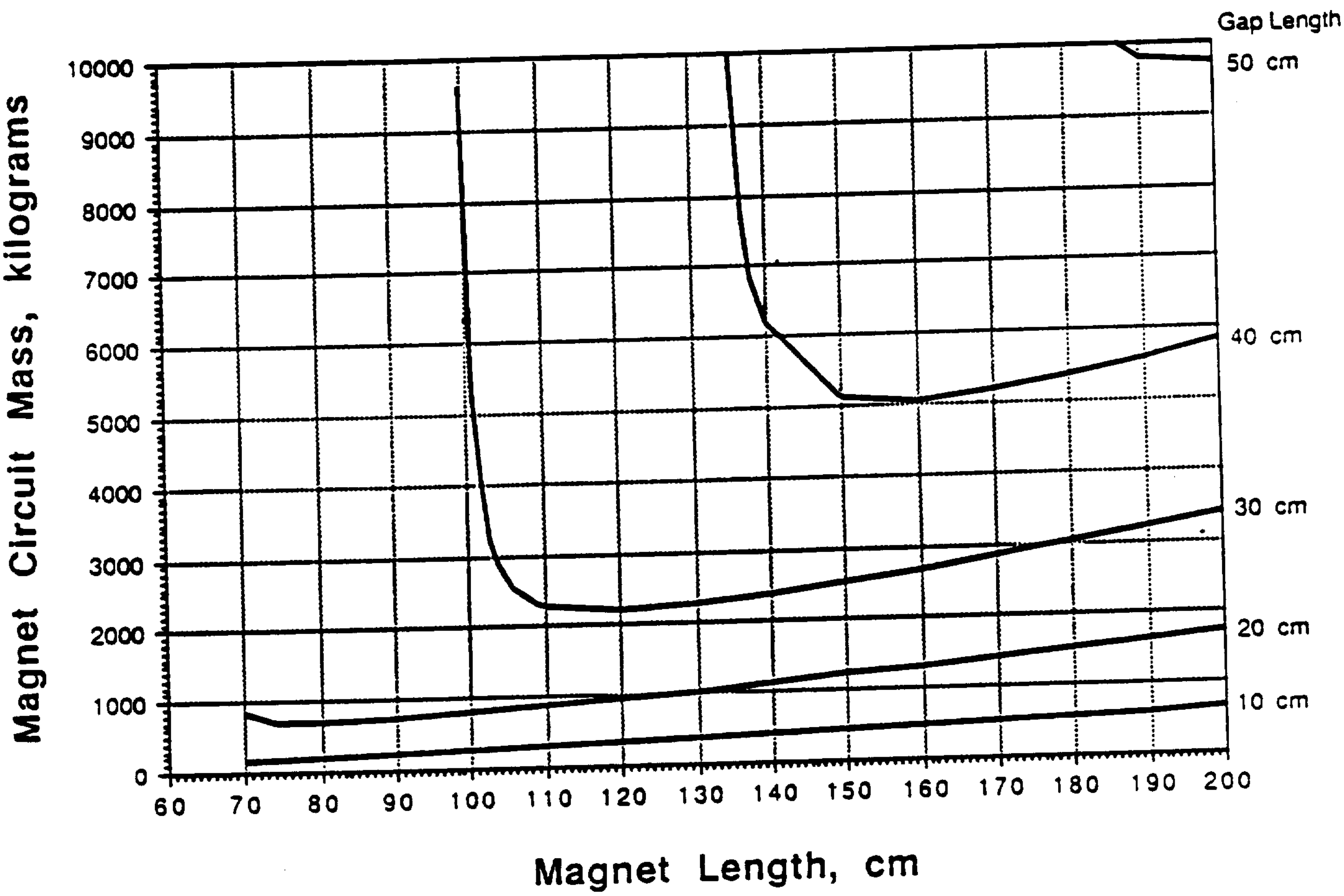


FIGURE 2.1-21. PLOT OF CIRCUIT MASS VS MAGNET LENGTH FOR ALNICO V

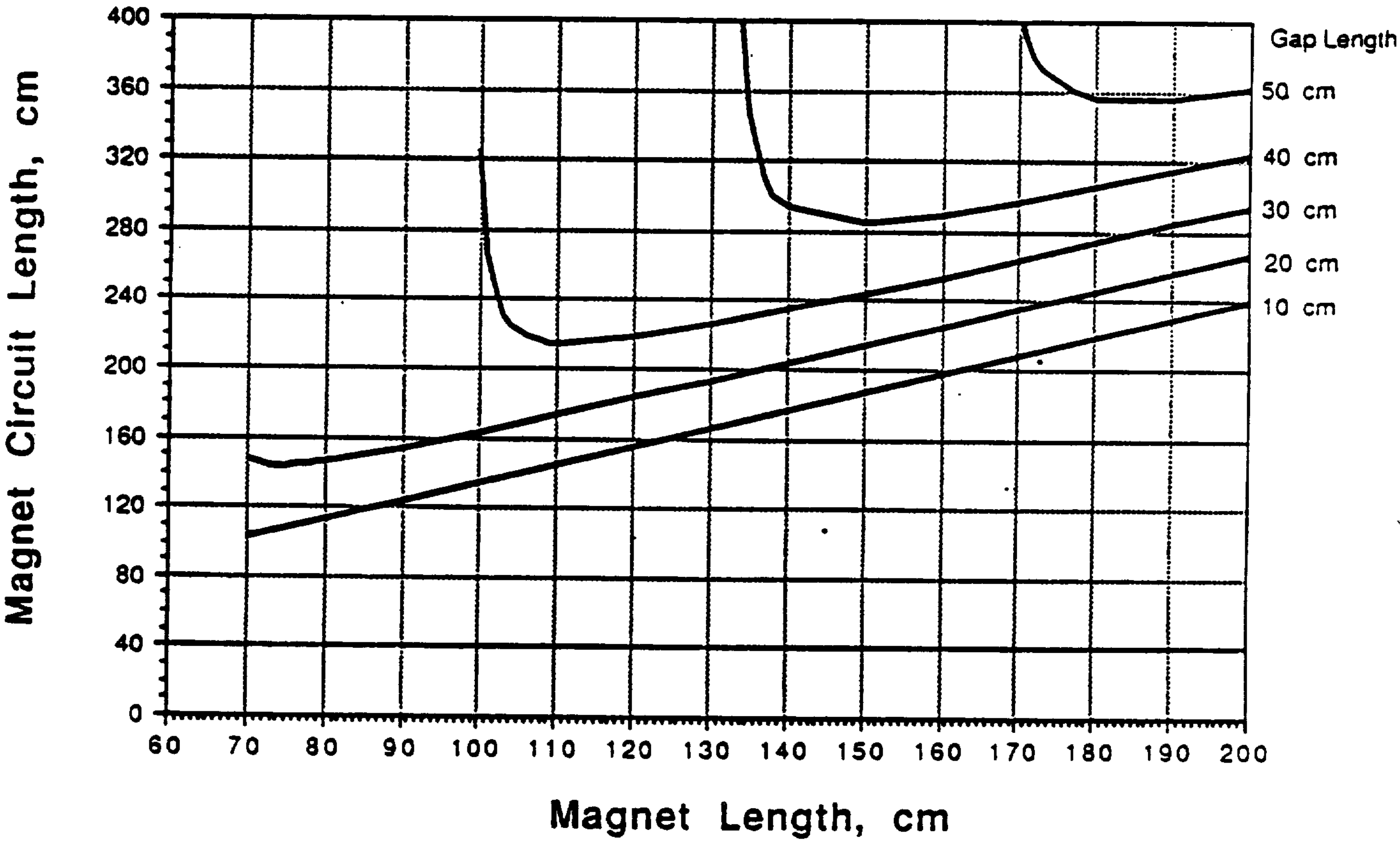


FIGURE 2.1-22. PLOT OF CIRCUIT LENGTH VS MAGNET LENGTH FOR ALNICO V

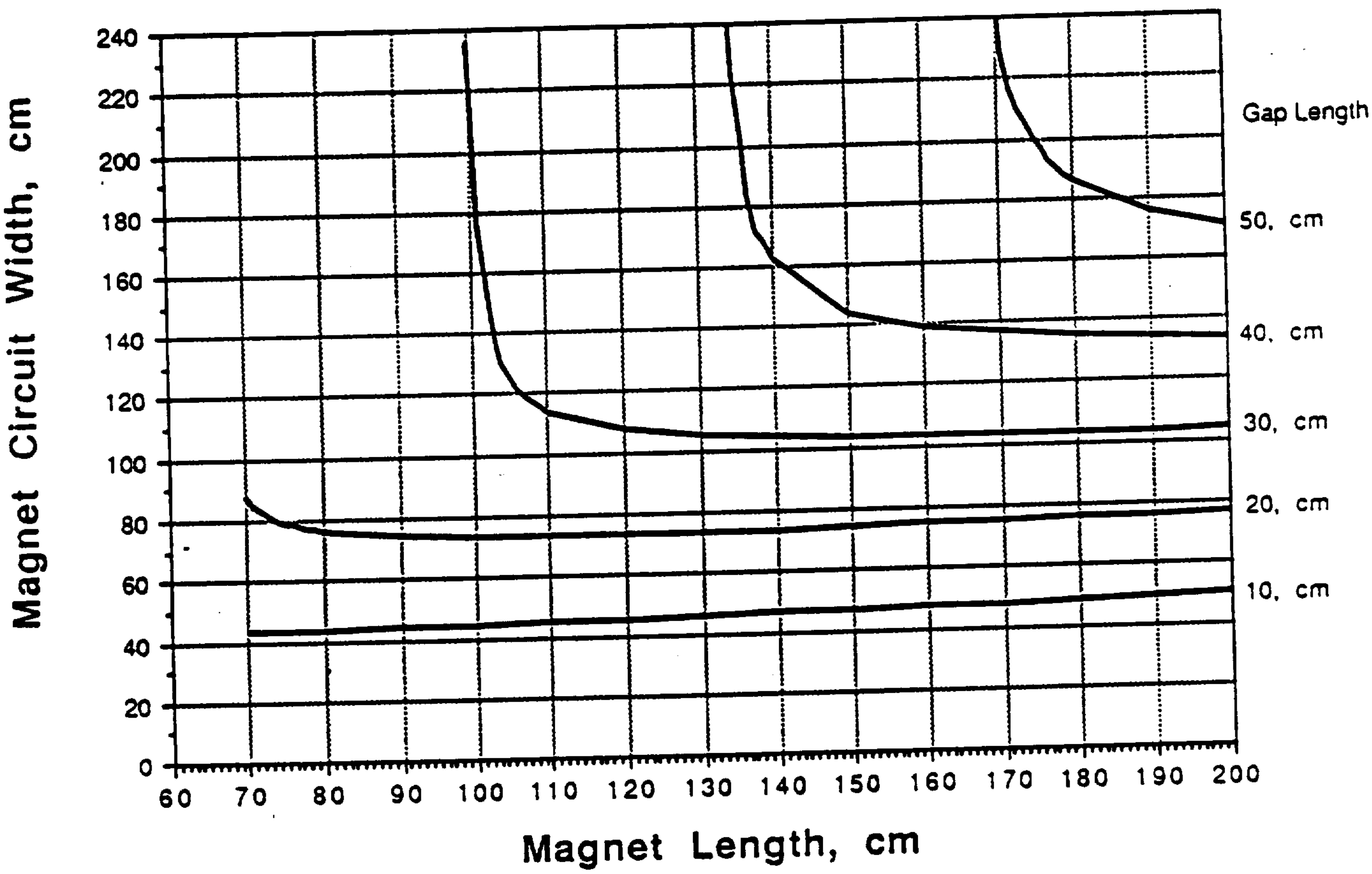


FIGURE 2.1-23. PLOT OF CIRCUIT WIDTH VS MAGNET LENGTH
FOR ALNICO V

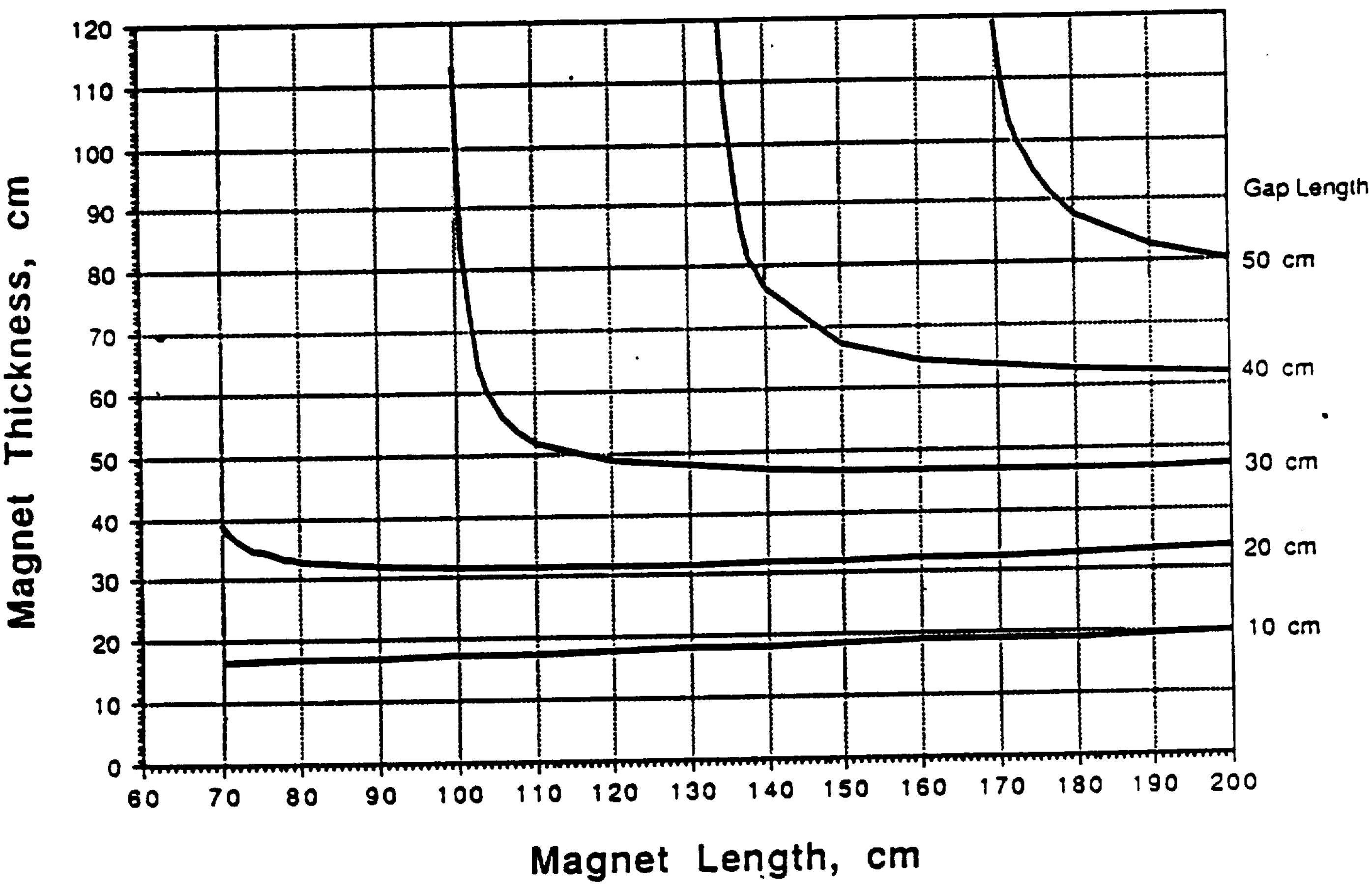


FIGURE 2.1-24. PLOT OF MAGNET THICKNESS VS MAGNET LENGTH FOR ALNICO V

magnet length, and Figure 2.1-25 is a plot of total permeance versus magnet length. Each of these plots include curves for various gap lengths. These same plots are presented for NdFe24 in Figures 2.1-26 through 2.1-30. From Figure 2.1-21, the circuit mass has a minimum value at a certain magnet length. This happens because the total permeance is a function in part of the magnet area-to-length ratio. Thus the minimum values for each gap length represent sort of an optimum value. Comparing Figure 2.1-21 and Figure 2.1-26 shows that the NdFe24 magnet has its optimum values at lower magnet lengths than the Alnico V. This is consistent with the fact that NdFe24 has a greater maximum energy product that the Alnico V, meaning it is generally a "stronger" magnetic material. Thus, NdFe24 is the material of choice for minimizing mass and volume. To accommodate a furnace module 50 cm in height, a gap length of at least 50 cm is required. Figure 2.1-21 shows that, for a 50-cm gap length, the circuit has its minimum mass of approximately 4,000 kg at a magnet length of 45 cm. Using Figure 2.1-22, for a magnet length of 45 cm, the circuit length is approximately 260 cm, and from Figure 2.1-23, the circuit width is approximately 220 cm. The circuit width sets the inside diameter of the shield to be used. From Figure 2.1-16 for a shield inside diameter of 220 cm the shield thickness will be greater than 80 cm (by extrapolation), which will result in a shield mass of perhaps 10,000 kg. Thus, to use a permanent magnet, the gap size in the circuit considered must be very small to become feasible from a mass and volume standpoint.

The resource requirements, shown in Table 2.1-20, for the concept utilizing a permanent magnet were based on accommodating a furnace module with an outside diameter of 20 cm and an overall length of 50 cm. The requirements were estimated for a system with an emitted magnetic flux of 1.0 gauss as well as for 0.3 gauss.

Normal Electromagnet System Concept

Concepts for using a normal electromagnet have been examined in this study. The most viable concept is shown schematically in Figure 2.1-31. The concept consists of a solenoid-type electromagnet with a clear bore to accommodate the furnace module. The electromagnets are commonly constructed of a copper wire coil wound around a cylindrical form made of a nonmagnetic metal. The windings are insulated with an epoxy or lacquer. The

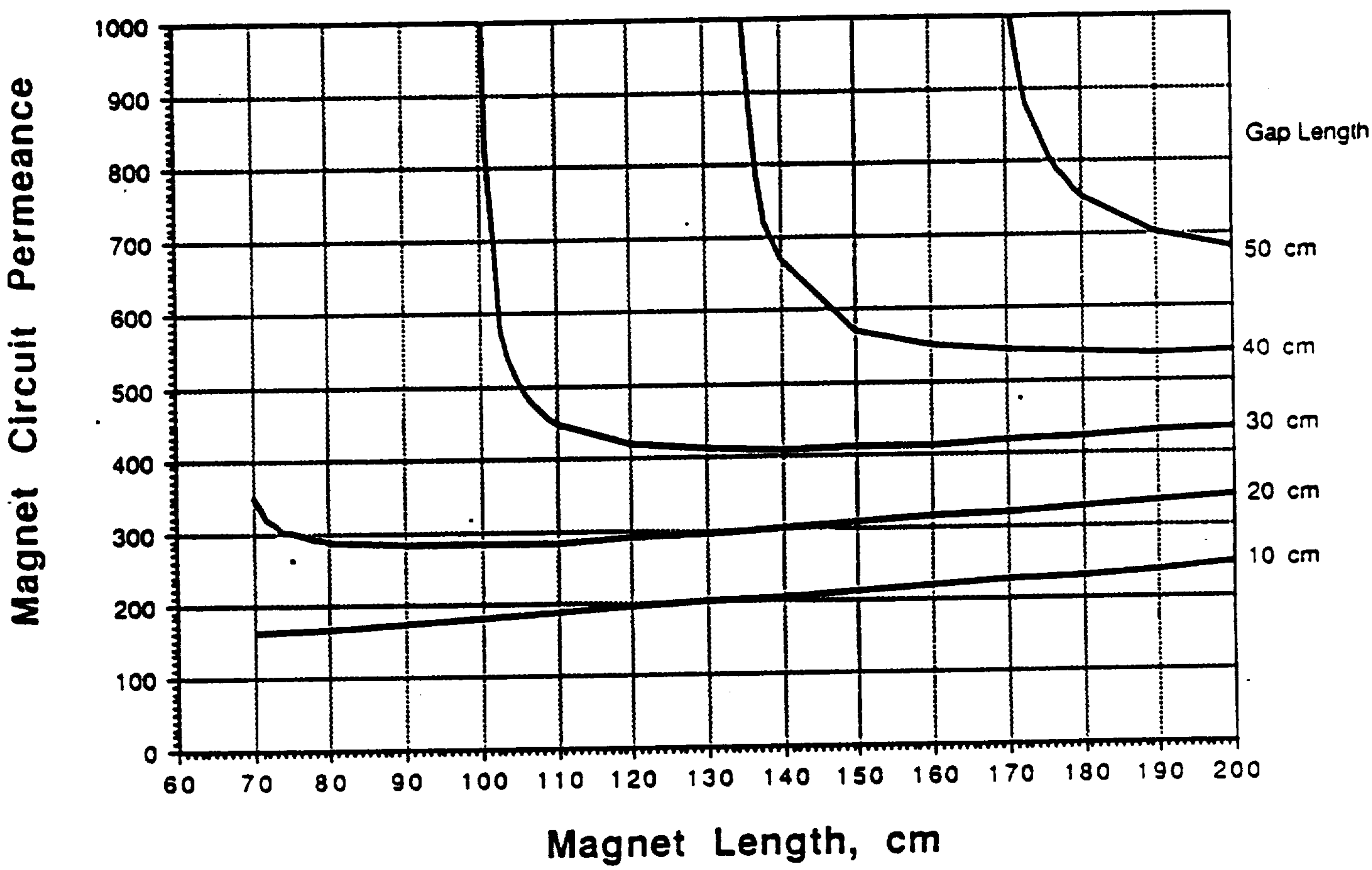


FIGURE 2.1-25. PLOT OF CIRCUIT PERMEANCE VS MAGNET LENGTH FOR ALNICO V

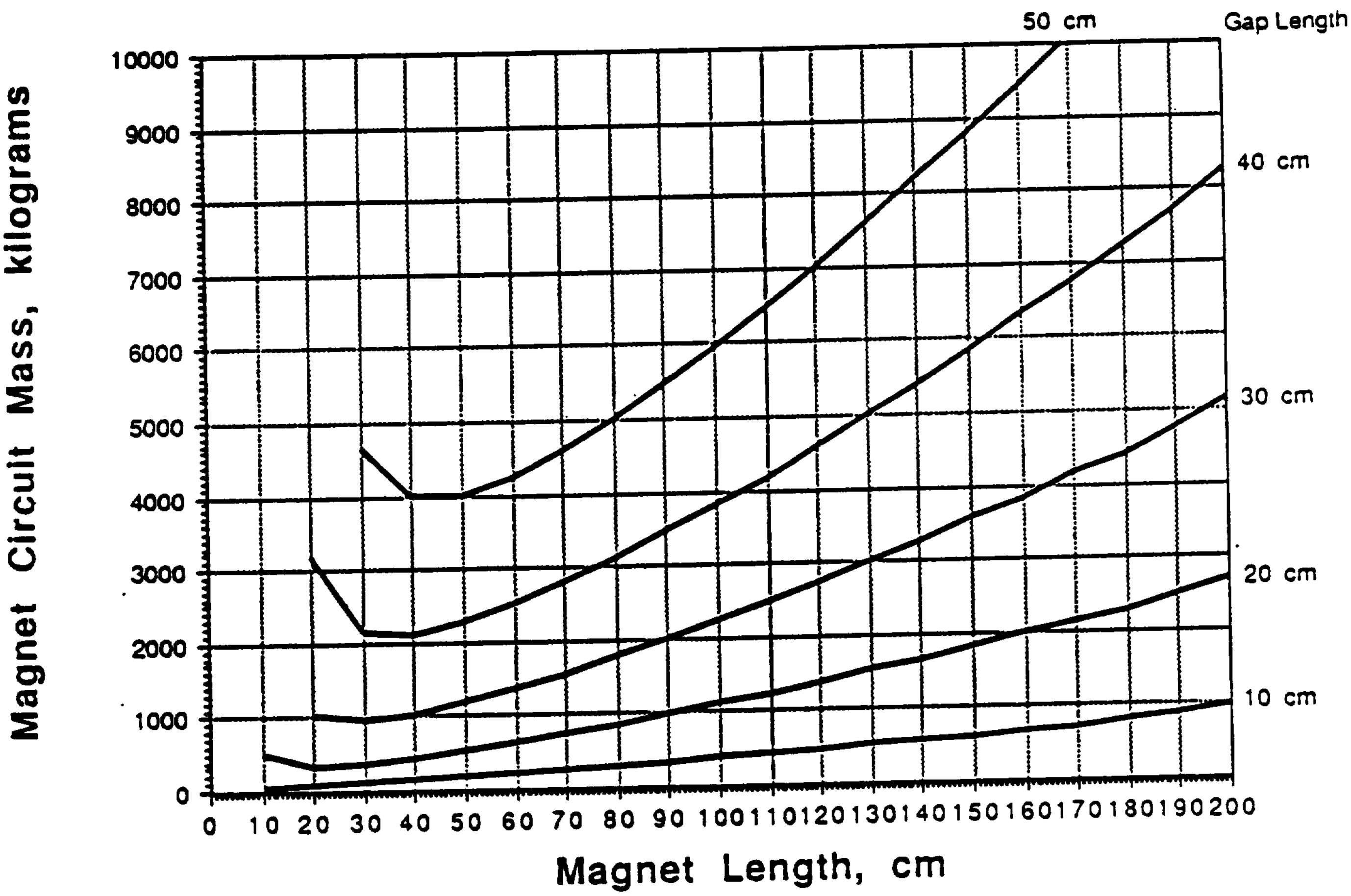


FIGURE 2.1-26. PLOT OF CIRCUIT MASS VS MAGNET LENGTH FOR NdFe24

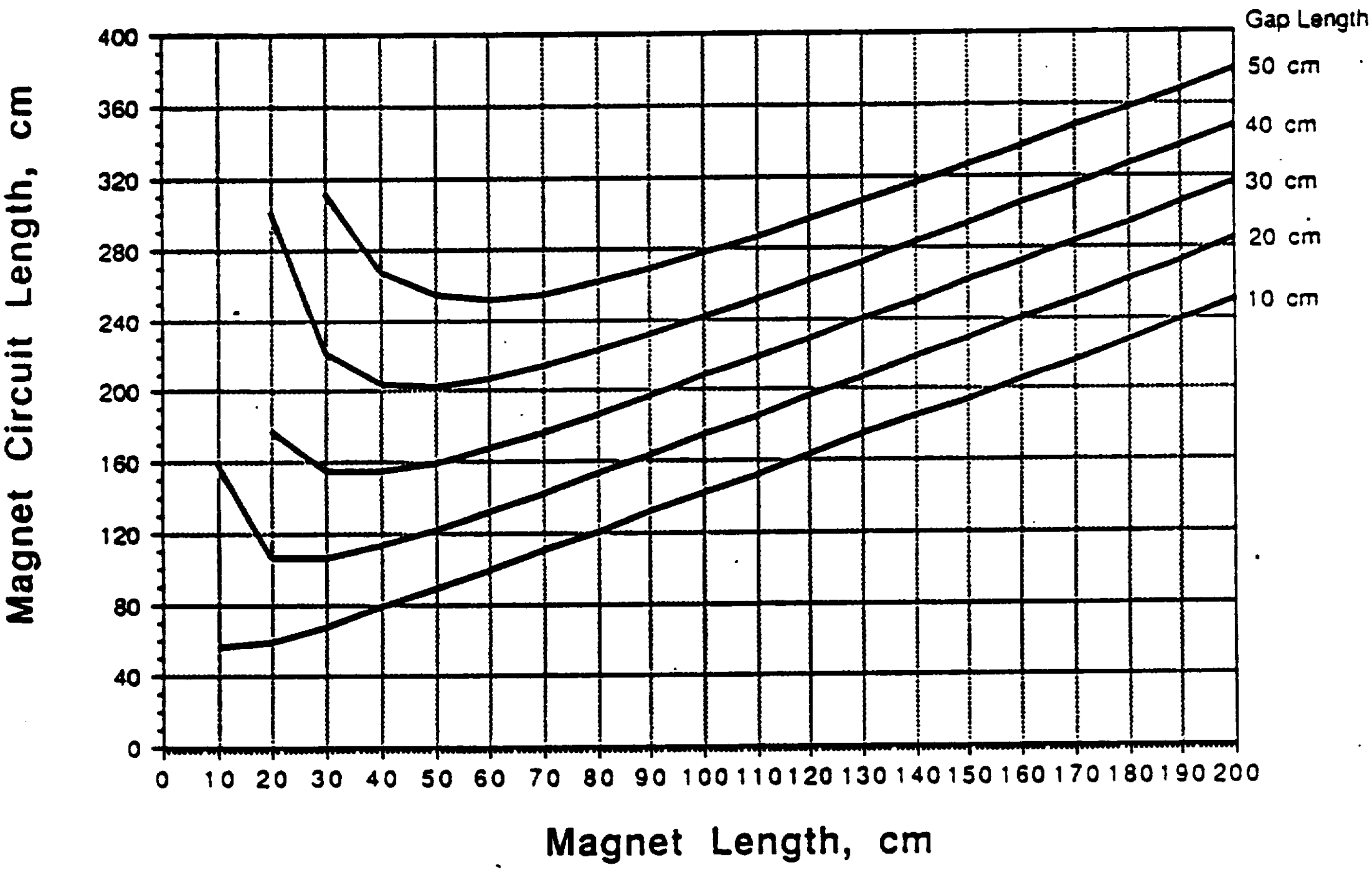


FIGURE 2.1-27. PLOT OF CIRCUIT LENGTH VS MAGNET LENGTH FOR NdFe24

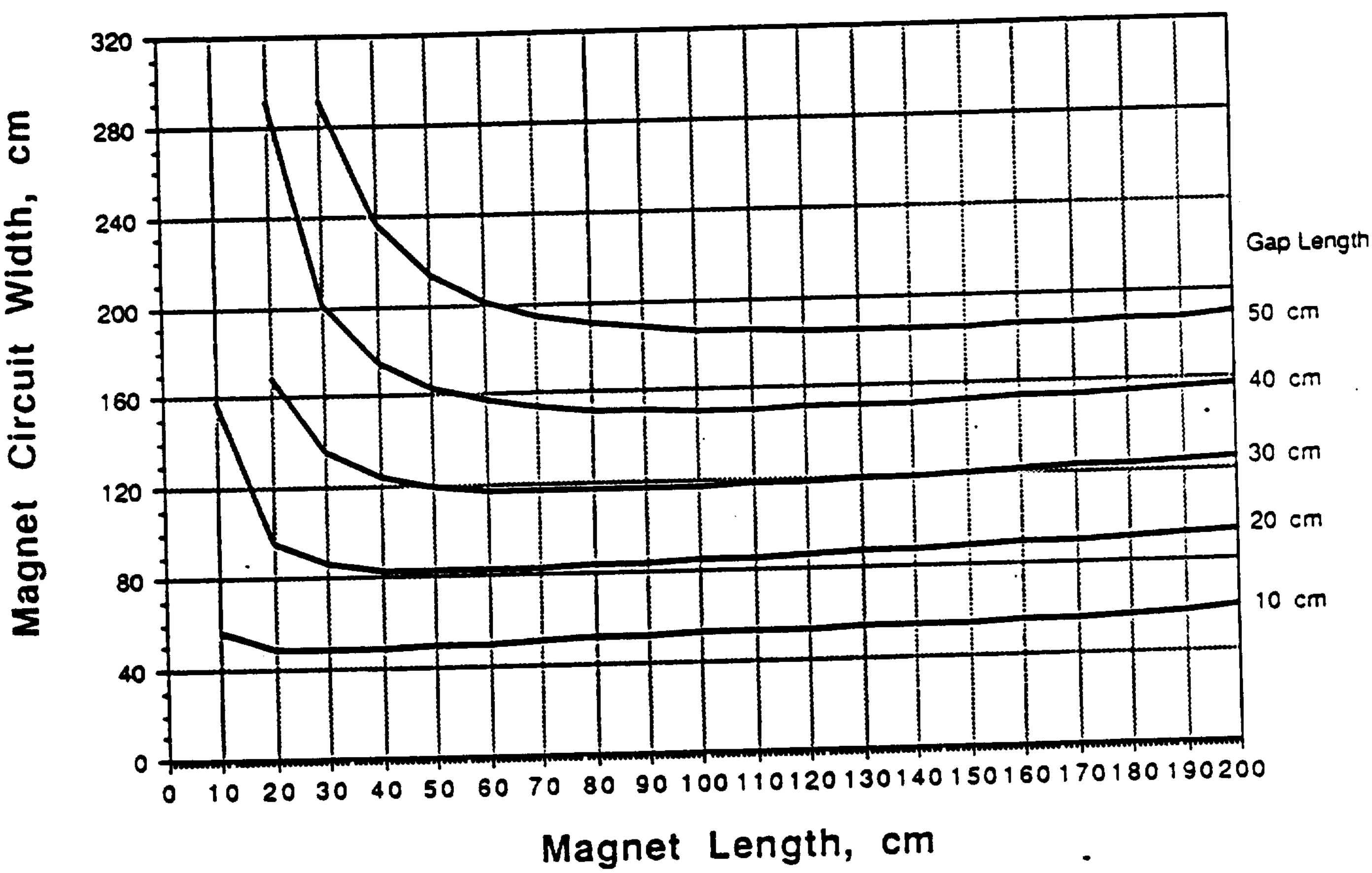


FIGURE 2.1-28. PLOT OF CIRCUIT WIDTH VS MAGNET LENGTH FOR NdFe24

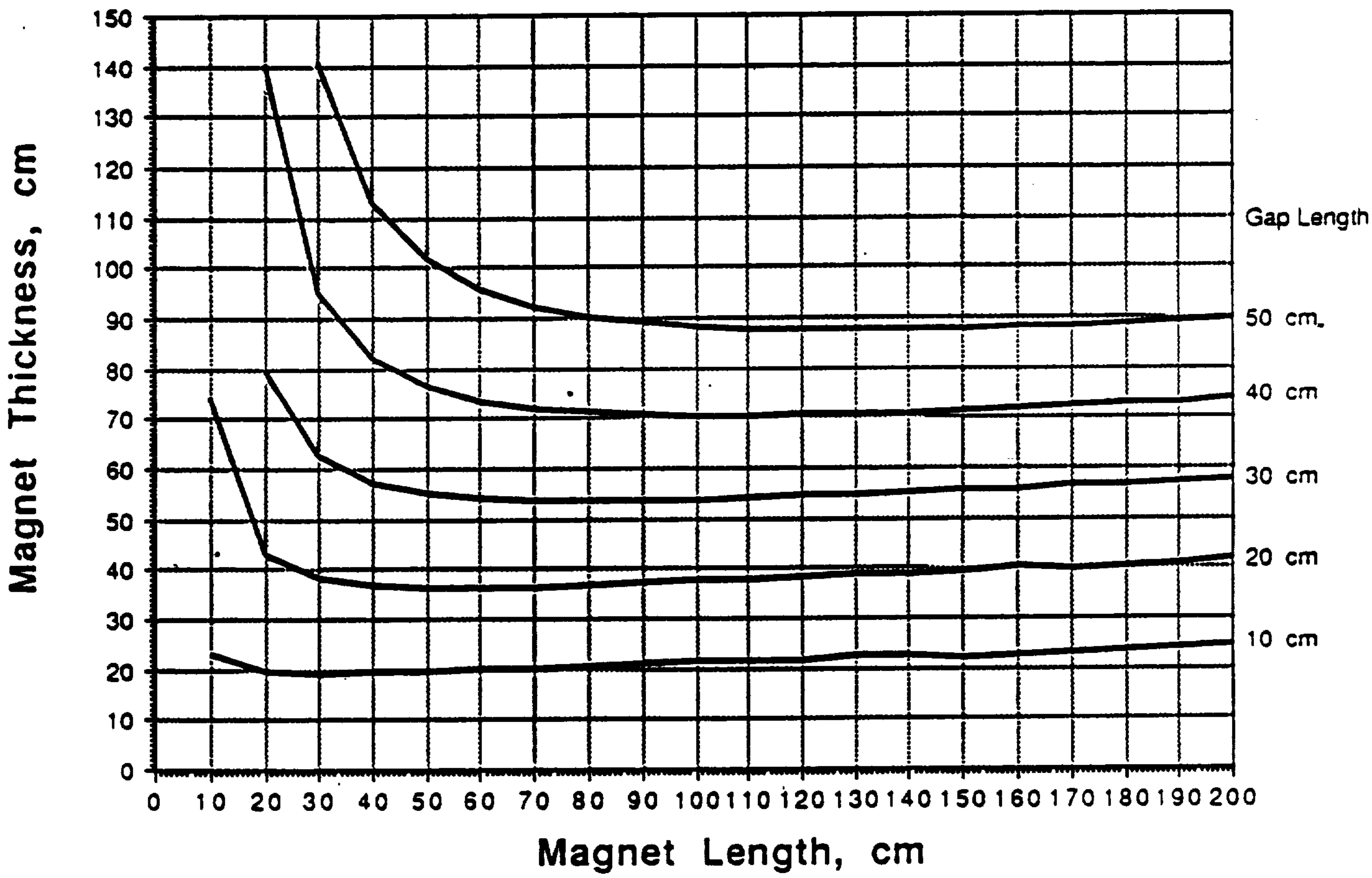


FIGURE 2.1-29. PLOT OF MAGNET THICKNESS VS MAGNET LENGTH FOR NdFe24

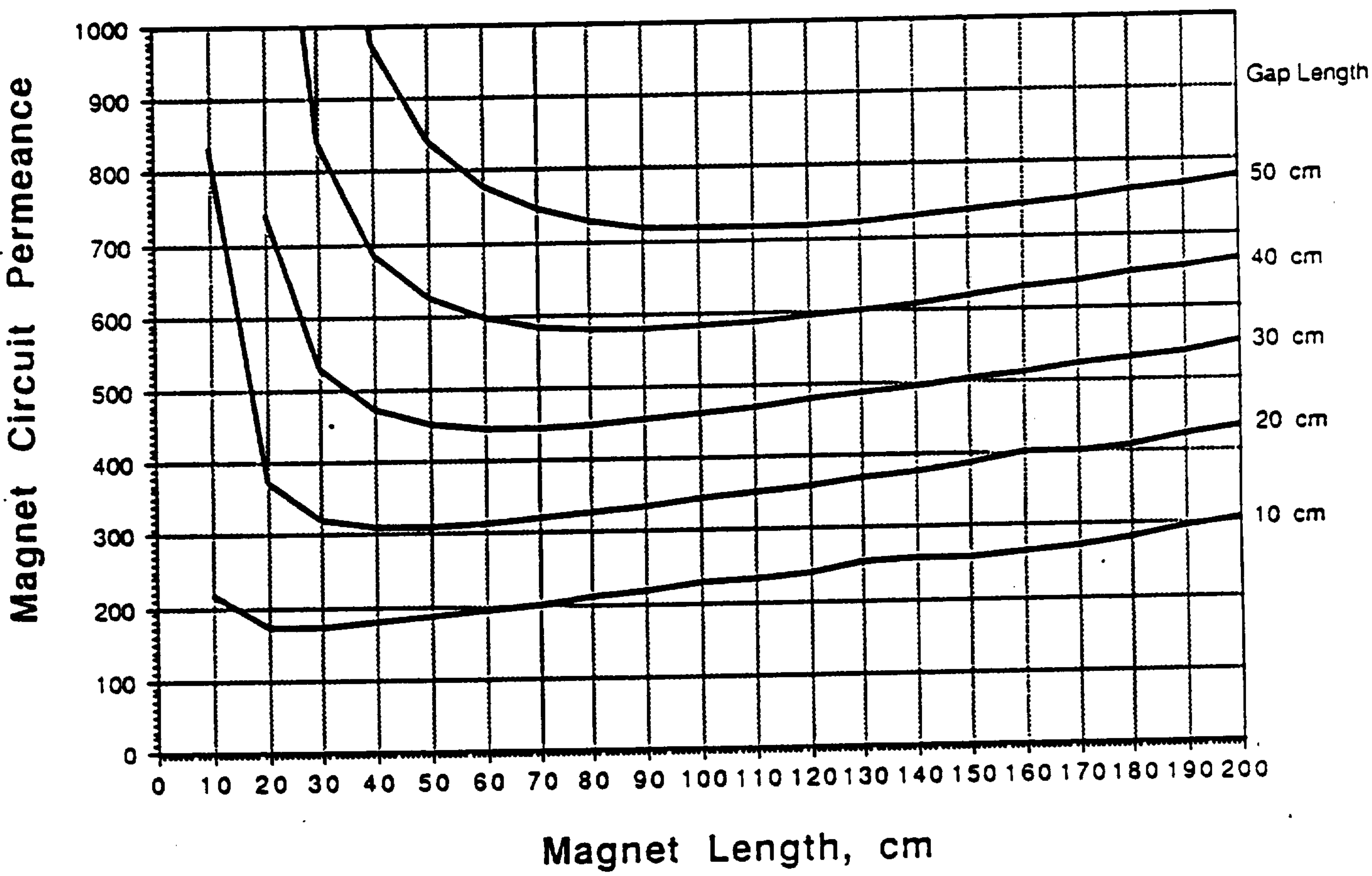


FIGURE 2.1-30. PLOT OF CIRCUIT PERMEANCE VS MAGNET LENGTH FOR NdFe24

TABLE 2.1-20. RESOURCE REQUIREMENTS

Mass and Volume Requirements	The overall mass of this concept will be in excess of 10,000 kg. The system will be approximately 450 cm high and 400 cm wide.
Power Requirements	None
Thermal Requirements	None
Data Requirements	The data requirements for this concept are well within the scope of the SSFF capabilities.
Venting Requirements	None
Consumables	None

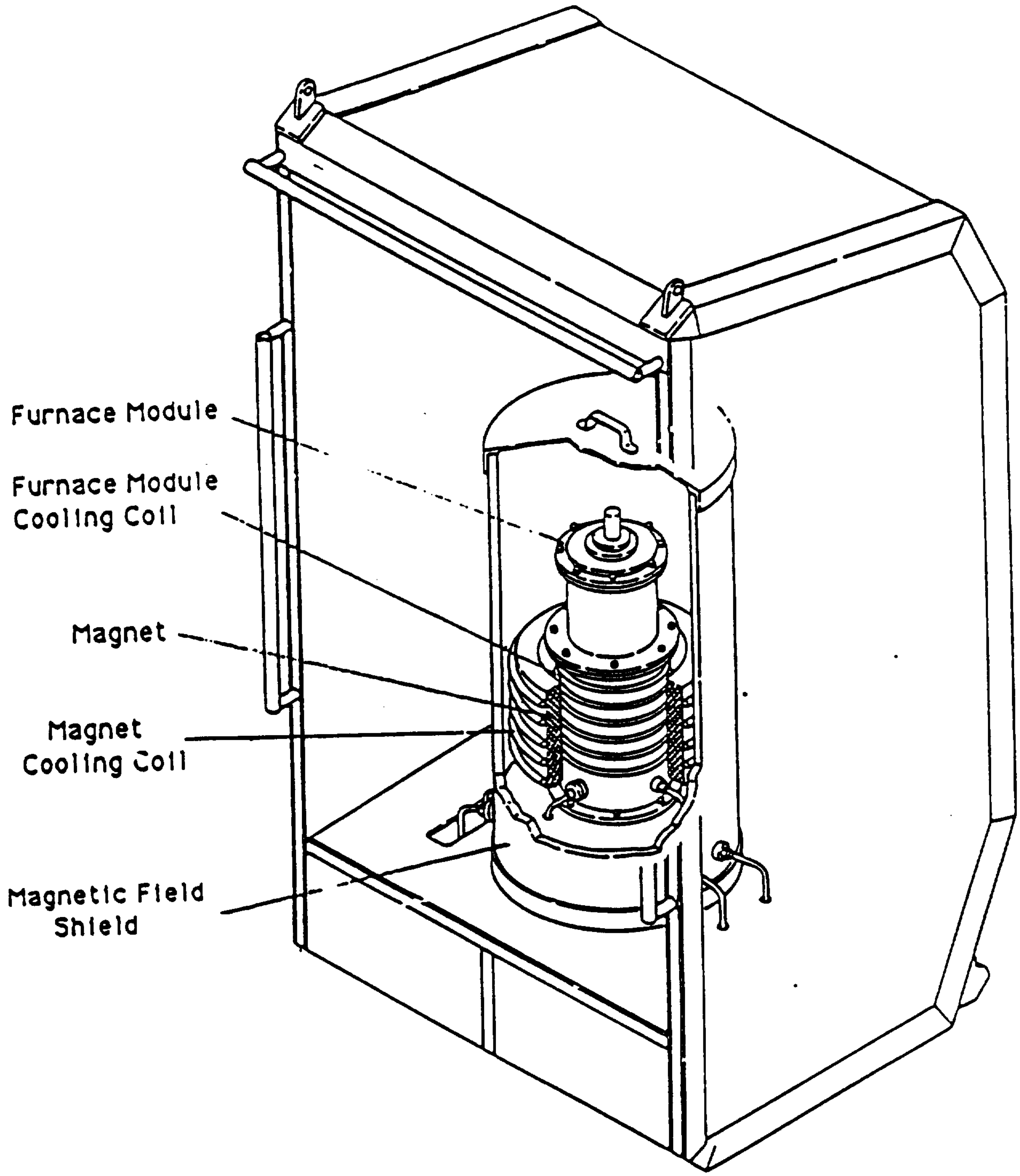


FIGURE 2.1-31. ELECTROMAGNET CONCEPT

height of the magnet coil in this concept is sufficient to cover the melting zones of the furnace module under consideration. The magnetic field is set up by passing a current through the copper conductor. This magnet can operate at room temperature so a refrigeration system is not needed. Heat is generated by the coil, however, which will require an active cooling system to prevent overheating of the conductor. The electromagnet has a water jacket through which cooling water is passed to maintain the magnet within its proper temperature range. The magnetic field can be varied by adjusting the current flow through the copper coil. In addition to the magnet coil and the cooling subsystem, a power supply is also required which will probably be included in the SSFF Core. For this concept, resource requirements were estimated and are discussed in Table 2.1-21 for various system sizes.

The resource requirements for the concept utilizing a solenoid-type electromagnet were based on accommodating a furnace module with an outside diameter of 20 cm and a hot zone length of 20 cm. It was assumed that the overall height of the furnace module was 60 cm. The form used for the coil winding was constructed of aluminum and was assumed to be 0.254 cm thick. The magnet wire used in the coil winding was constructed of copper. The requirements were estimated for a system with an emitted magnetic flux of 1.0 gauss as well as for 0.3 gauss.

2.1.7 Rack Structures

The SSFF has been allocated five double rack locations in the USL module. The SSFF Core is the only component of this facility currently defined as requiring the standard payload rack envelope. The SSFF Core is composed of subsystems common to all of the Furnace Modules in the facility. The individual Furnace Module mounting requirements are currently undefined.

The objective of this study is to identify and determine the relative merits of mounting the Furnace Module in a standard rack as opposed to developing a special rack-mounting structure peculiar to the Furnace Module requirements.

TABLE 2.1-21. MASS AND VOLUME REQUIREMENTS (Sheet 1 of 3)

Mass and Volume Requirements	For a given magnet coil diameter and coil height, it was found that for a desired magnetic flux at the center of the solenoid the mass of the coil will vary inversely with the power delivered to the coil. This is illustrated in Figure 2.1-32, which is a plot of magnet coil mass versus power input to the coil for a 2,000 gauss magnetic flux at various coil inside diameters. As can be seen from Figure 2.1-32, there is a tradeoff between the mass of the coil and the power requirement. For a 20-cm diameter furnace module, and a power requirement of 1,000 W, the mass of the coil is approximately 135 kg. Figure 2.1-33 is a plot of the outer diameter of the magnetic coil versus the the power input for various coil inside diameters. For a 1000-W power input and an inside diameter of 20 cm, the outside diameter of the coil is approximately 44 cm. The outer diameter of the coil is governed by the number of turns in the coil, the coil height and the diameter of the wire used in the coil. Thus, the overall outside diameter of the coil is 44 cm, which means that the inside diameter of the magnetic shield must be at least 44 cm. Using Figure 2.1-14, which is a plot of the emitted magnetic flux versus the required thickness of the magnetic shield, for a shield with an inside diameter of 44 cm and constructed of Alloy 1, the required thickness for an emitted flux of 0.3 gauss is approximately 14.1 cm. For an emitted flux of 1.0 gauss, the required shield thickness is approximately 13.6 cm. There is not much difference between the two values since for both thicknesses, the flux in the shield material will be above the saturation value of 7,500 gausses. This can be verified using Figure 2.1-17, which shows that for a shield with an inside diameter of 44 cm, the minimum shield

TABLE 2.1-21. MASS AND VOLUME REQUIREMENTS (Sheet 2 of 3)

Mass and Volume Requirements (Conc.)	thickness to avoid saturation of the material is approximately 15 cm. Using Figure 2.1-16, for a shield with an inside diameter of 44 cm and a thickness of 14.1 cm, the shield mass is approximately 1300 kg. Thus, the overall outside diameter of the magnetic shield is approximately 72.2 cm for an emitted magnetic flux of 0.3 gauss and 71.2 cm for an emitted flux of 1.0 gauss. Using Figures 2.1-32 and 2.1-33, the power and mass requirements for an electromagnet to accommodate other furnace module diameters can be determined as was done in this case for a 20-cm diameter furnace module.
Power Requirements	In this study, it was assumed that 120 Vdc power will be supplied to the electromagnet. Figure 2.1-32 shows that there is a tradeoff between the power requirement for the electromagnet and the mass of the electromagnet. A power requirement of 1000 W was selected which should be viable since the furnace module will also require a certain amount of power which will depend on its design. Using Figure 2.1-32 however, the mass requirement for this concept can be determined for other power levels if desired.
Thermal Requirements	As mentioned above, the electromagnet will require active cooling. This is because of the joule heating of the magnet wire. The rate of heat removal must be at the same rate that it is produced to prevent the temperature from increasing. Assuming a temperature difference of 25 °F between the inlet and exit temperatures of the cooling water flowing in the water jacket surrounding the electromagnet, to provide 1,000 W of cooling, approximately 62 kg/h of cooling water is required.

TABLE 2.1-21. MASS AND VOLUME REQUIREMENTS (Sheet 3 of 3)

Data Requirements	There are no stringent data requirements envisioned for this concept except in the area of ensuring that the magnetic flux emitted from the system does not exceed the specified limit of 0.3 gauss. If there are fluctuations in the current delivered to the electromagnet, the magnetic flux produced will also fluctuate and emissions could exceed the limiting value. For this reason, the current must be monitored and provisions put in place to control the effects of current surges which may impact the data requirements of this concept.
Venting Requirements	None
Consumables	None

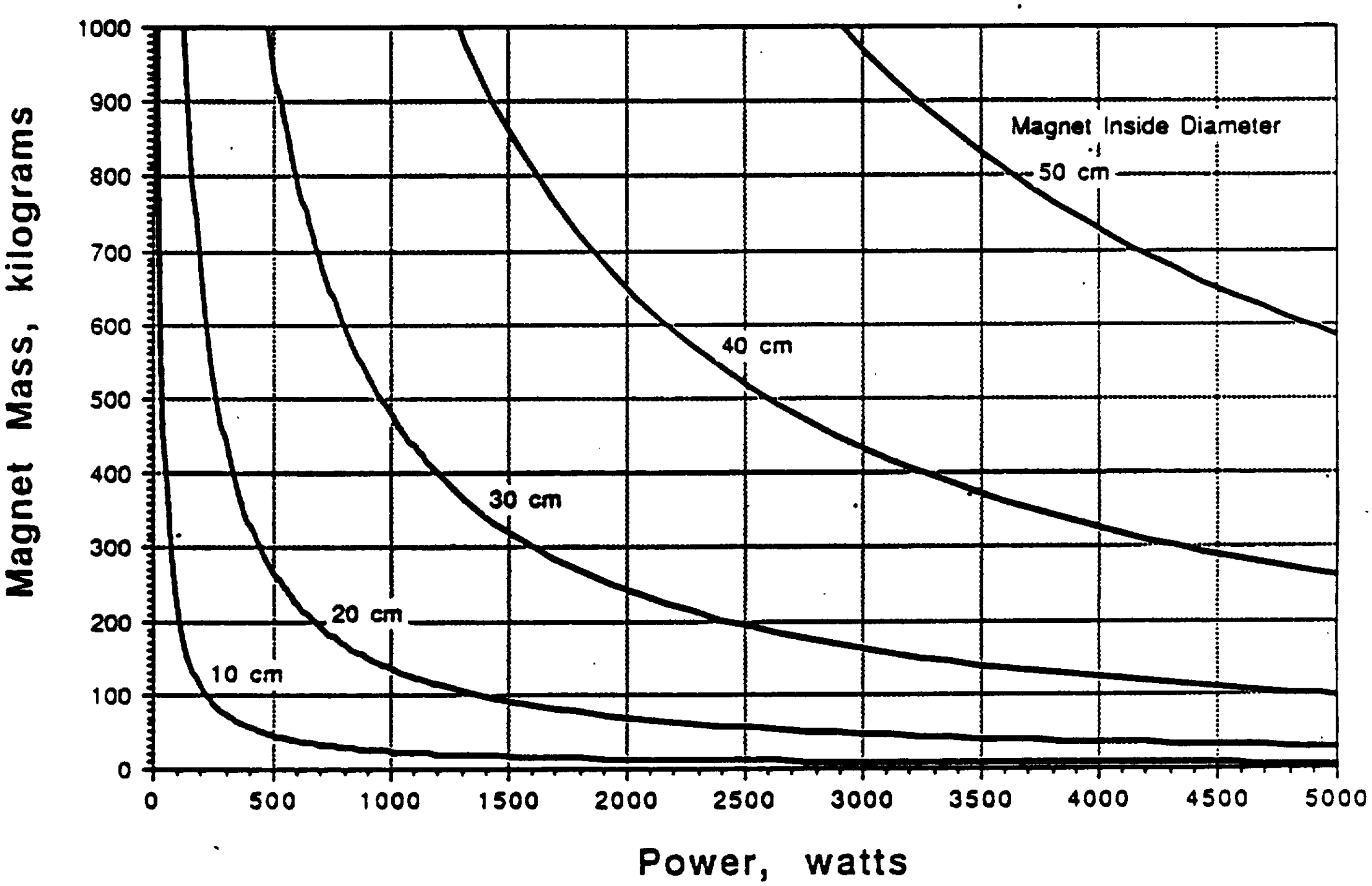


FIGURE 2.1-32. PLOT OF MAGNET MASS VS POWER

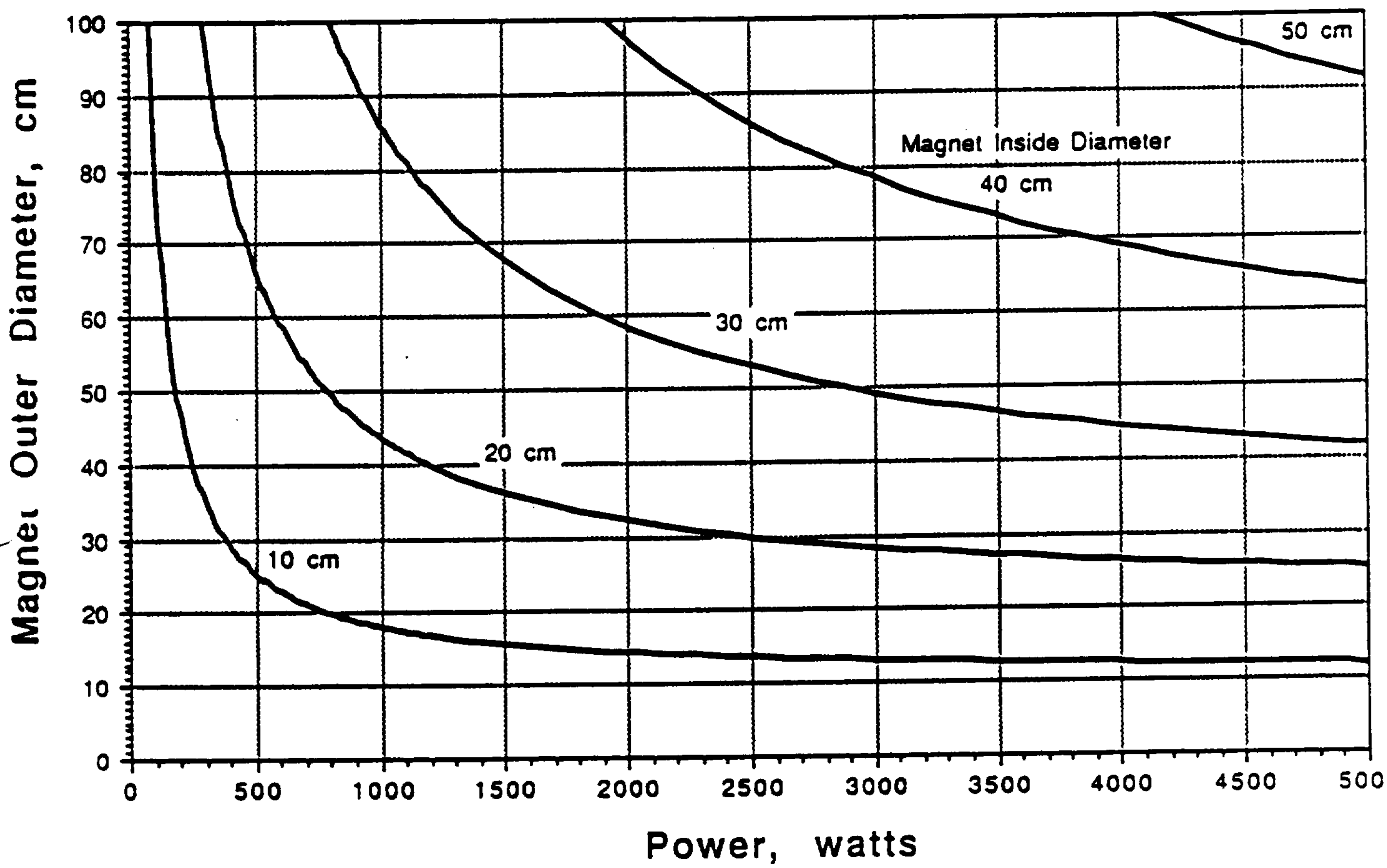


FIGURE 2.1-33. PLOT OF MAGNET OUTER DIAMETER VS POWER

Furnace Mounting Requirements

The current design concepts for the candidate Furnace Modules call for the furnace containers to be base mounted using a mounting flange. Each Furnace Module container mounting flange would conform to a standard bolt circle. The Furnace Module EAC flange will mate with an attachment flange integral with the rack attachment structure. The rack attachment structure may be a standard payload rack incorporating the mounting plate or it may be a special structure designed only to locate and support the Furnace Module. This study will identify issues involved in this trade.

The advantages and disadvantages of using the standard rack are as follows:

- Advantages
  - No new hardware development is required other than a mounting adapter structure
  - Special problems associated with Furnace Module transportation logistics are avoided. The Furnace Modules are flown up to the station in the standard rack.
- Disadvantages
  - An equipment rack design is not required for the Furnace Module.
  - The Furnace Modules are designed to be base mounted; the current rack configuration is more suited for front-mounted equipment.
  - Because of the first two items above, the standard rack will have to be modified with a base mounting platform to accommodate the Furnace Modules. This modification makes the standard rack a nonstandard item.
  - If furnace alignment with the residual g-vector is required, an alignment gimbal must be attached to the rear wall of the rack structure. This modification may require a nonstandard rack structure.
  - The standard rack configuration allows very little clearance between the top of the Furnace Module EAC and the rack upper surface. On the CGF furnace, the overhead clearance is only 8 in., which is insufficient for removal or insertion of

sample ampoules. The top of the EAC can only be accessed by removal of the EAC from the rack or tilting the EAC out into the lab module aisle. The base mounting attachment may therefore have to include a pivot point to allow tilting the Furnace Module for ampoule insertion and removal.

The advantages and disadvantages of the nonstandard rack mounting structure are as follows:

- Advantages
  - The structure can be optimized for the purpose of supporting the Furnace Module.
  - No upper rack structure is required if the load reactions can be properly distributed among the lower attachment points.
  - Elimination of the rack structure allows ready access to the lab module wall in the event of a hull breach.
  - A furnace orientation system is more easily accommodated.
  - Elimination of the rack structure improves access to the Furnace Module EAC.
  - The standard rack cost may be eliminated.
  - Total furnace launch mass can be optimized by eliminating unused components in the rack structure.
- Disadvantages
  - The nonstandard structure development and qualification may be cost prohibitive.
  - The nonstandard support structure may not prove adequate as a launch container for the Furnace Modules requiring a separate logistics carrier.
  - The nonstandard structure may be driven towards a standard rack-type structure to properly distribute the load reactions between the upper and lower attachment points on the lab module wall.

Conclusions

No conclusion can be reached at this time because of the immaturity of the rack design and the Furnace Module configurations.

2.1.8 Thermal Control Subsystem

The objective of the SSFF Thermal Control Subsystem (TCS) is to provide the thermal heat sink for the Furnace Modules included in the facility as well as heat loads of the coldplate-mounted electronics in the core rack. This subsystem is composed of a water loop, which performs the following functions.

- Collection of heat dissipated by the Furnace Modules
- Collection of heat dissipated by the electronics in the core rack
- Heat transport
- Rejection of heat to the SSF Lab Customer Thermal Control System.

The SSFF TCS will use WP-01 components where possible to ensure cost effectiveness and efficiency. A schematic of the TCS in a Space Station rack is shown in Figure 2.1-34, which shows the major components of the subsystem. It is expected that the components of the subsystem will reside in the the rear of the rack behind the coldplate-mounted SSFF Core Electronics. A schematic of the water loop is shown in Figure 2.1-35. This schematic shows the configuration with a 24,000-W capacity. The water loop collects heat from the Furnace Modules and core rack electronics. The collected heat is then transferred to the Space Station TCS via the heat exchangers.

The TCS will be evolutionary in that its capabilities will be scaled up with the growth of the SSFF. The initial configuration of the subsystem will have an 8,000-W capacity. As shown in Figure 2.1-35, this initial configuration will have only one of the branches containing the pumps and heat exchangers. When growth beyond 8,000 W is needed, the second pump and heat exchanger branch is added and later the third branch is added to get the 24,000-W capacity.

The subsystem incorporates parallel rack flow to allow independent service to the Furnace Modules and the Core electronics. Each Furnace Module can be isolated from the system. The Core rack coldplates are connected in series as shown in Figure 2.1-36.

Flow control in the loop is maintained by the two flow controllers which regulate the flows in the particular branches. These flow controllers will consist of an arrangement of solenoid operated trim and check valves to control

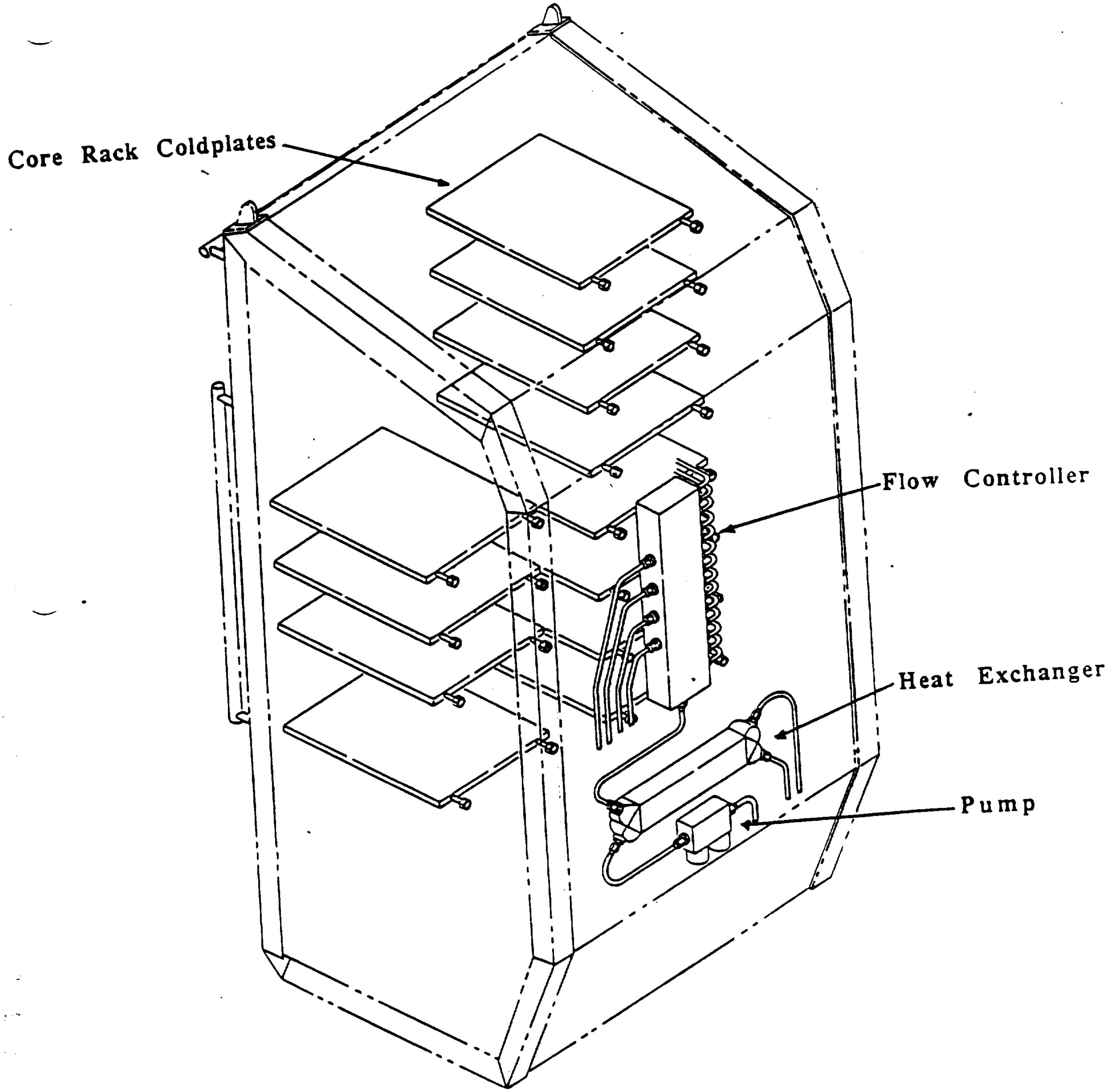


FIGURE 2.1-34. SCHEMATIC OF THERMAL CONTROL SUBSYSTEM IN RACK

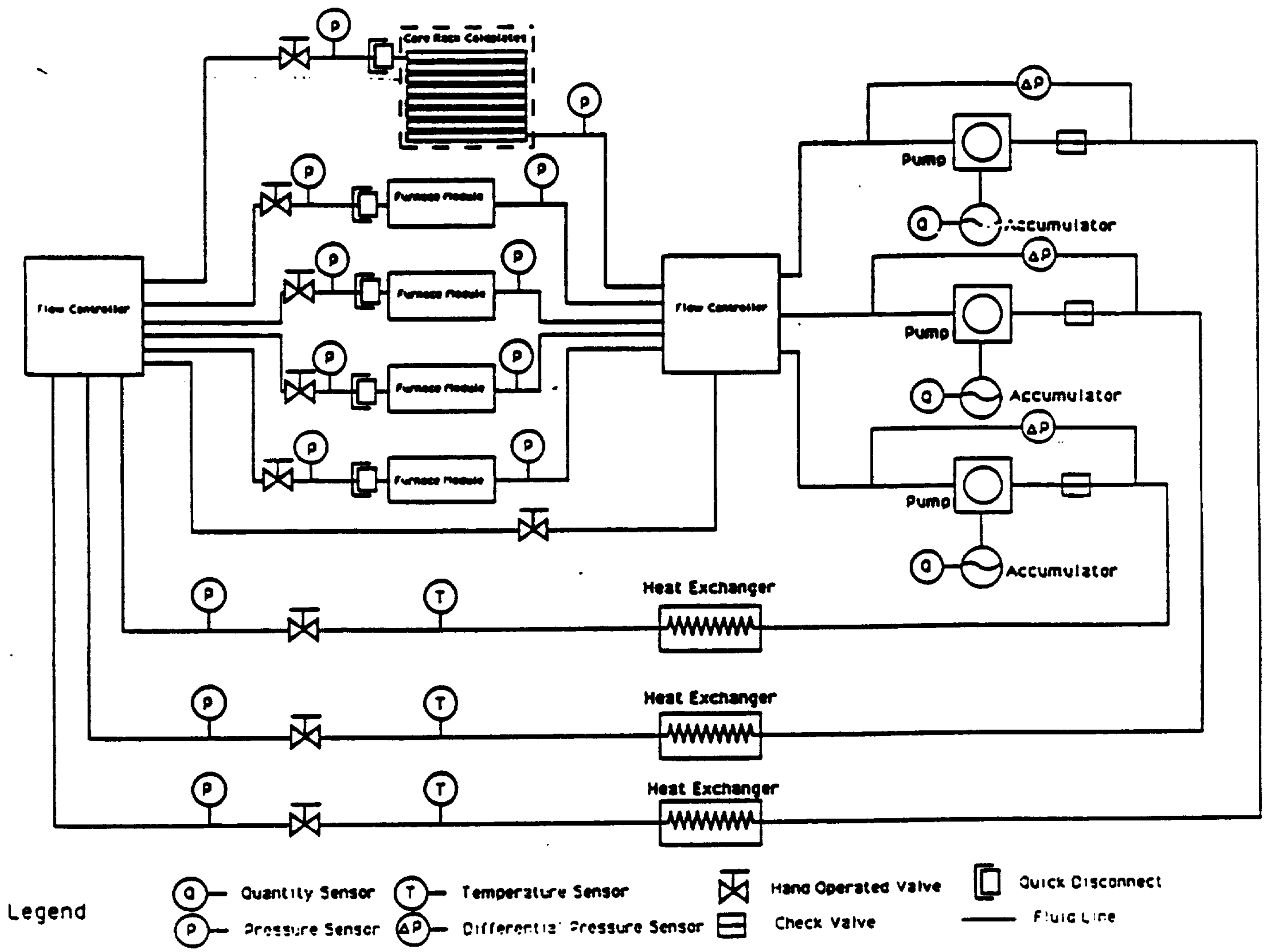


FIGURE 2.1-35. SCHEMATIC OF THERMAL CONTROL SUBSYSTEM WATER LOOP

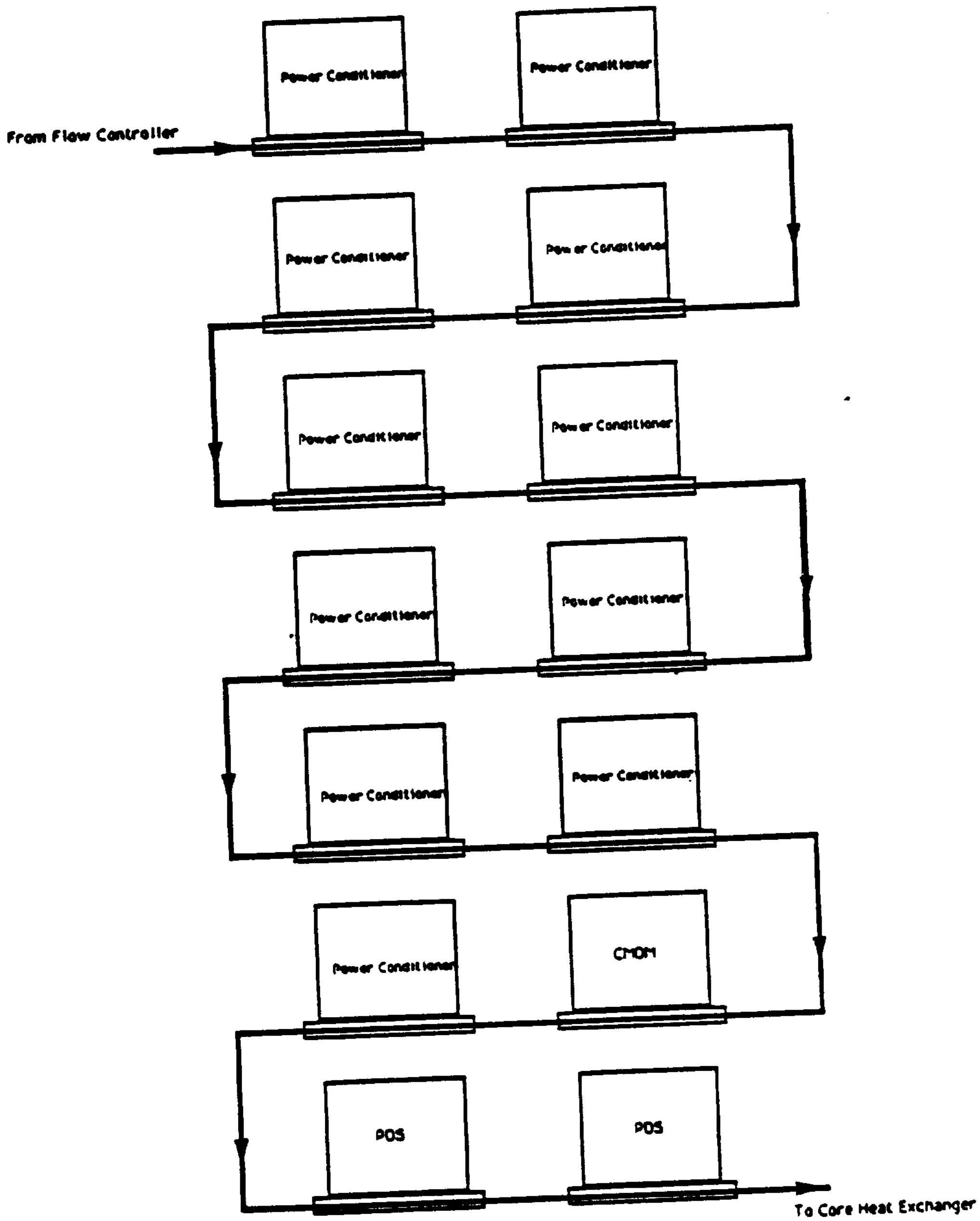


FIGURE 2.1-36. CORE RACK COLDPLATE CONFIGURATION

the flow. The flow controllers will be equipped with sensors to monitor flow rates, temperatures, and pressures at various points.

The heat exchangers used are expected to be the 8000-W heat exchangers used in the WP-01 TCS design. These heat exchangers operate at a design flow rate of 1,100 lb/h with an effectiveness of 0.92 and a design pressure drop of 0.5 psi. The heat exchangers are 18 in. long, 8 in. high, and 4 in. wide.

The coldplates used in the core rack have not been selected, but the coldplates from WP-01 are being considered. These coldplates have three sizes but all have a design pressure drop of 0.6 psi and a design conductance of 1.62 W/in^2/°F.

The pump packages circulate the water through the loop, and each consists of an inlet filter, an electrically powered centrifugal pump, and a reverse flow check valve. Sensors are included to monitor fluid inlet and outlet temperatures and pressure rise across the package. An accumulator is included with each pump to compensate for thermal expansion within the water loop and maintains positive water pump inlet pressure. A sensor monitors the accumulator water quantity.

Hand-operated valves are included throughout the loop to provide manual control if necessary. Performance data for the TCS are given in Table 2.1-22.

The resource requirements of the TCS were estimated and summarized in Table 2.1-23.

2.1.9 Fluids Distribution System

The SSFF is modular facility consisting of five double racks for SSF. This facility will be designed for crystal growth and solidification research in the fields of electronic and photonic materials, metals and alloys, and glasses and ceramics. Several furnaces are being studied for incorporation in the SSFF concept. This is a preliminary conceptual design of the SSFF Fluids Distribution System (FDS). A conceptual design of this system can be seen in Figure 2.1-37.

The variety of furnaces to be used in the SSFF require many different resources to properly execute their objectives as shown in the block diagram in Figure 2.1-38. They will all require very sophisticated control methods to

TABLE 2.1-22. PERFORMANCE DATA FOR THERMAL CONTROL SUBSYSTEM

Maximum Heat Rejection Capability	8 kW (24 kW Growth)
Water Loop Flow Rate	TBD
Water Temperature Range:	
Minimum	75 °F
Maximum	100 °F
Power Consumption	60 W
Heat Dissipation	60 W (nominal)
Maximum Operating Pressure	200 psi
Fluid Leakage	TBD
Total Pressure Drop	20 psi

TABLE 2.1-23. RESOURCE REQUIREMENTS

Physical Properties	The volume and mass properties of the equipment in the TCS were estimated from equipment used in similar systems and the common equipment in WP-01.
• Mass	
- Heat Exchangers	35.40 kg
- Coldplates	34.86 kg
- Plumbing	100.00 kg
- Pump Packages	284.40 kg
Total	454.66 kg
Power	The only component of the TCS requiring power is the pump package. It is estimated that its power requirement will be 60 W.
Thermal Requirements	The heat dissipated by the pump package is expected to have a nominal value of 60 W. This heat load is expected to be removed by avionics air.
Consumables	TBD
• Data	
- Number Of Channels	85
- Average Samples/sec	1
- Peak Samples/sec	20
- Average Data Rate	2 kb/sec
Data Requirements	The instrumentation and data requirements of the TCS are presented in Table 2.1-24.

TABLE 2.1-24. DATA REQUIREMENTS FOR THERMAL CONTROL SUBSYSTEM

IDENTIFICATION	QTY	SAMPLING RATE Hz
Temperature Sensors	24	1
Pressure Sensors	24	1
Delta Pressure Sensors	3	1
Quantity Sensors	3	1
Solenoid Valves	10	1
Flowrate Sensors	10	1

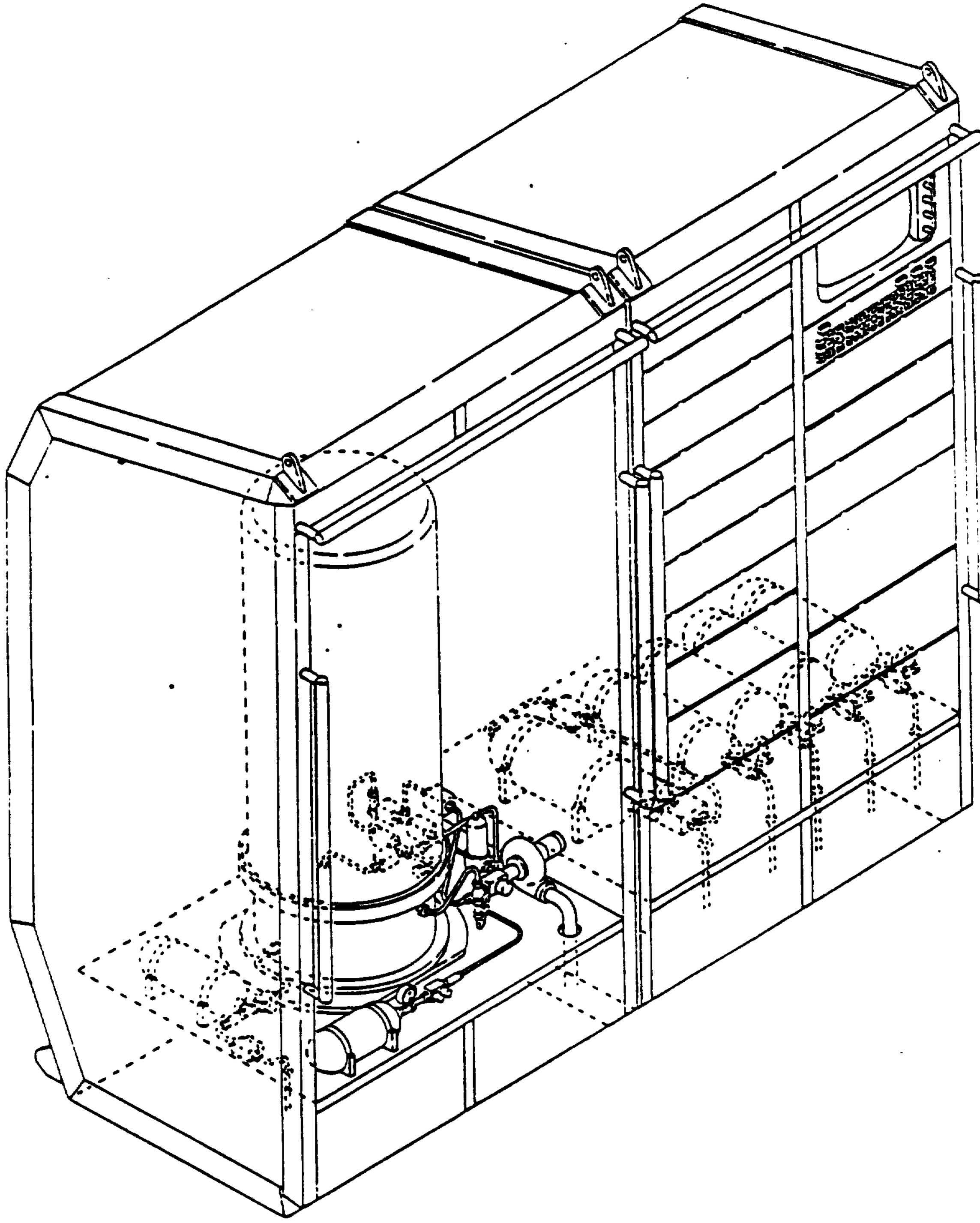


FIGURE 2.1-37. FLUIDS DISTRIBUTION SYSTEM

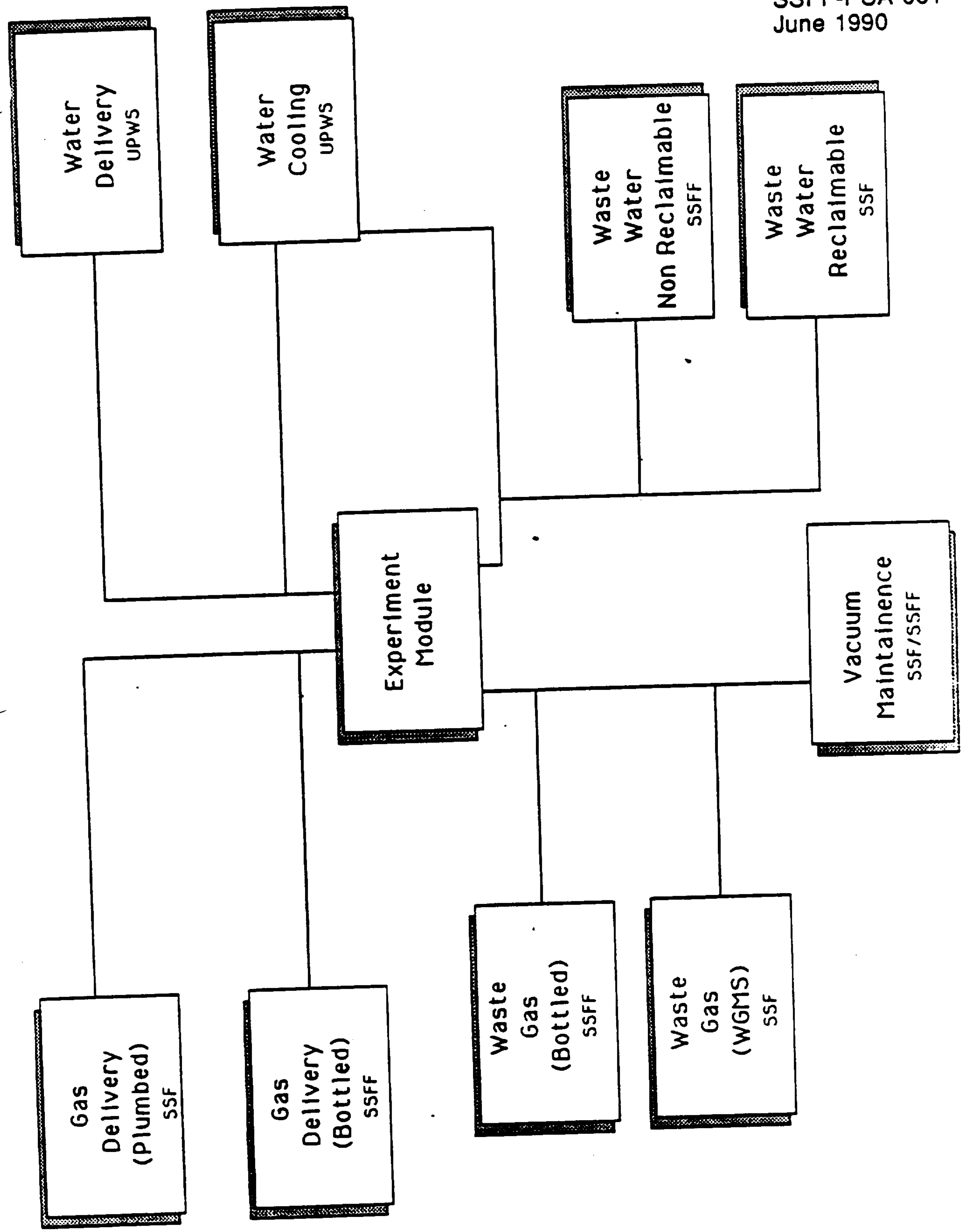


FIGURE 2.1-38. SSFF FLUID SERVICE BLOCK DIAGRAM

ensure that experimental parameters are monitored and adjusted according to their individual needs. Some furnaces may require a facility to accurately align them in the direction of the Earth's residual gravity. In addition to these and other systems, the furnaces will require a system to provide them with an adequate supply of gases and liquids for processing, along with a vacuum and waste gas removal system. Most of the furnaces studied thus far have used argon as an inert gas for processing. In the future, some furnaces may require other gases such as oxygen or hydrogen.

Currently, the SSF Process Materials Management System (PMMS) will be providing only nitrogen and a vacuum level of 10^{-3} torr to the user community. Therefore, the SSFF FDS will be responsible for supplying all other gases required for processing of samples along with maintaining proper vacuum level, and management of waste fluids. The Science Capabilities Requirements Document (SCRD) calls for a vacuum level of 10^{-5} torr for the Furnace Modules. This report will discuss the methods available to meet the experimental requirements, and the factors in the design which could cause problems with the experiment or Space Station environment.

The FDS will interface with the Space Station PMMS at the nitrogen supply line, the Waste Gas Management System (WGMS), the Vacuum/Vent System, and the Ultrapure Water System (UPWS). There are two separate systems within the FDS. One system is responsible for supplying/removing gases, and one is responsible for supplying/removing liquids.

The FDS will supply processing gases and water to the Furnace Modules in the SSFF. It will use the supply of nitrogen from SSF PMMS in addition to user-supplied gases. Currently, SSF will supply N_2 to each rack at 90 psia, and SSFF user-supplied gases will be bottled at 1,000 to 1,500 psig (600 psig max for CO_2) and regulated down to 90 psia. The following is a description of the path followed by the gases through the system. A schematic of this system is shown in Figure 2.1-39.

First, the user must identify which gas will be required for processing of samples and the supply pressure needed. If N_2 is used, it will flow to the first solenoid valve at 90 psia. The valve is then opened and the N_2 flows to a 25-psia regulator, and from this regulator it will flow to a 20-3 psia variable (mechanical or electronic) regulator. The gas pressure can be adjusted at this

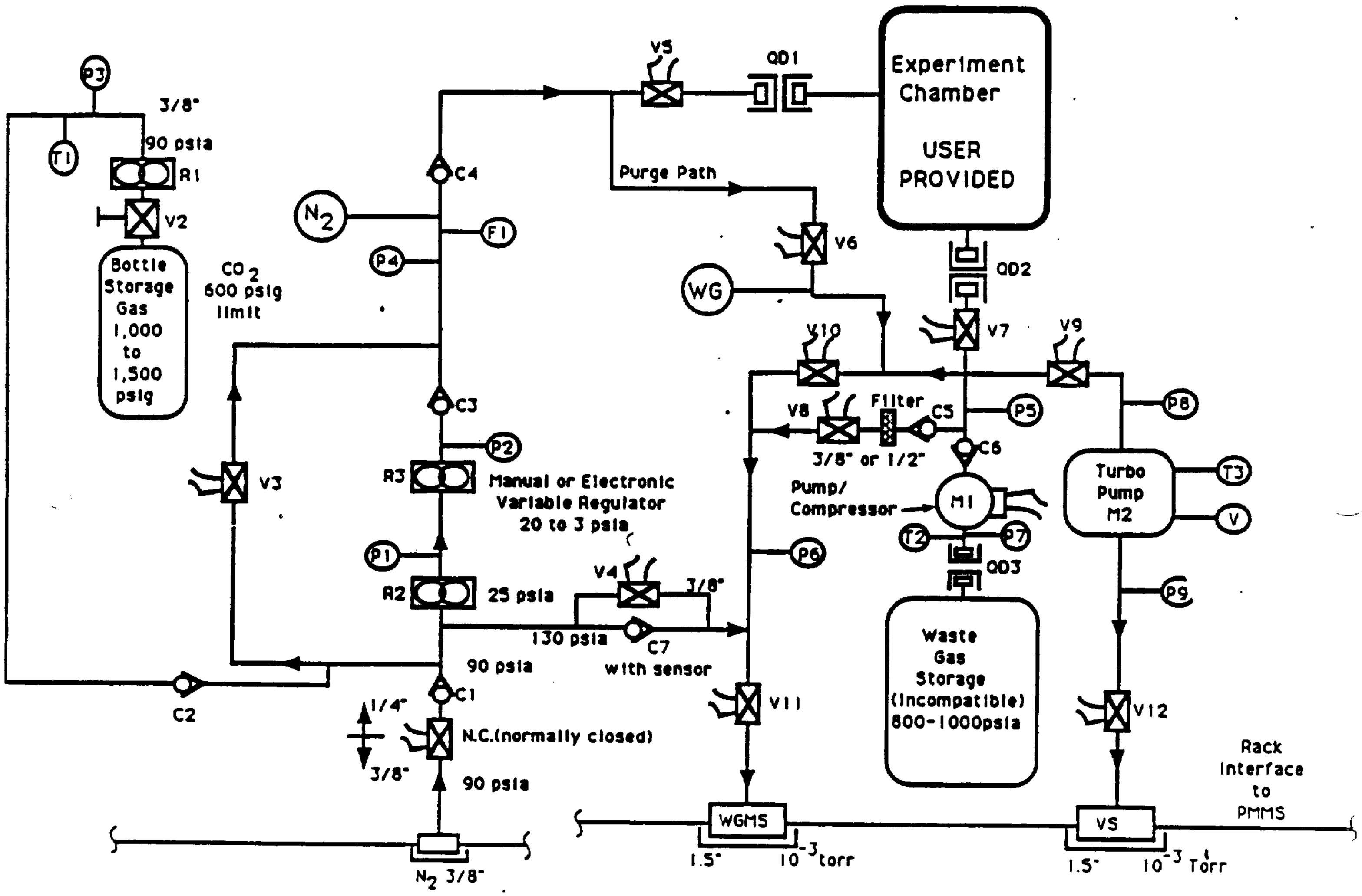


FIGURE 2.1-39. FLUIDS DISTRIBUTION SYSTEM
GAS DELIVERY/REMOVAL

point down to 3 psia. The N_2 will then enter the experiment chamber. Pressure sensors will monitor the N_2 at locations downstream of regulators, and check valves will be used to ensure that no backflow into the system occurs. The N2 enters the experiment chamber by passing through a solenoid valve and then through quick-disconnects (QDs) which attach the experiment chamber to the system.

The N_2 will then exit the experiment chamber through another QD, and after the gas has served its purpose, a gate valve will be opened to allow the gas to exit the chamber. When the waste gas exits the chamber, it will have three possible paths. The choice of path will depend on the user requirements or the ability of SSF to accept the gas.

The SCRD requires that a vacuum level of 10^{-5} torr must be obtainable in the SSFF. This vacuum level will require the use of a turbomolecular pump. The SSF can supply this vacuum level, but the level will fluctuate over time and hazardous materials cannot be vented. If the waste gas which exits the experiment chamber is sufficiently clean to enter directly into the WGMS, two gate valves may be opened and the gases will enter directly into the WGMS at a vacuum level of 10^{-3} torr. If the gases are not sufficiently clean, it can be directed through a filter which will scrub it to the desired cleanliness and then it will flow to the WGMS. However, SSFF must verify that all gases to be vented are nonhazardous at analytical integration. The ability to verify this could be a major design driver for the system. If SSFF cannot vent to SSF vacuum vent, a level of containment will be lost. If SSFF must vent hazardous materials, a waste storage bottle will be used to store the material. A compressor must be employed to pump the gases into the bottle, and compressors will cause a large number of low-frequency vibrations which would seriously threaten the ability to perform an ideal crystal growth experiment and would also seriously effect other experiments in the USL which rely on the low-g environment.

The FDS liquid delivery/removal system is responsible for handling water used by the furnace for processing. A schematic of this system is shown in Figure 2.1-40. It is not a replacement for the SSFF TCS. Some furnaces, such as the MASA, use a water quench system for rapid solidification. This

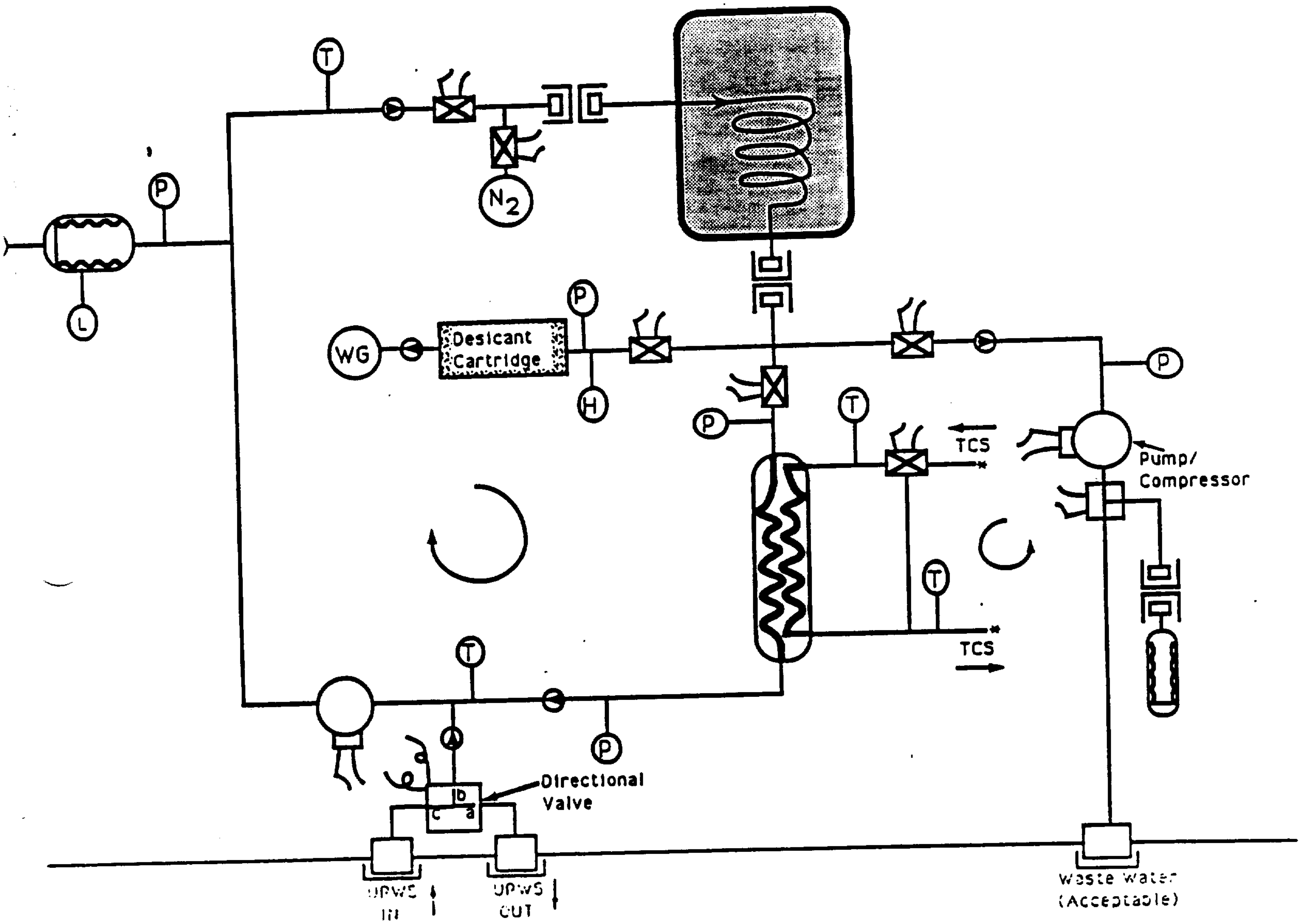


FIGURE 2.1-40. FLUIDS DISTRIBUTION SYSTEM
LIQUID DELIVERY/REMOVAL

system will be designed to accommodate these and other furnaces with a need for water.

The FDS liquid delivery/removal system delivers water from the SSF UPWS to a specially designed accumulator. The accumulator uses a bellows device to contain the water until it is needed in the furnace. After the UPWS supplies enough water to fill the bellows (2300 cc for MASA), a directional valve directs the water supply back into the UPWS. When the water is needed for a quench, pressure from a gas contained between the bellows and the accumulator walls will force the water from the accumulator through a regulator at a given pressure. The water will enter the quench block of the furnace and will then exit the experiment module. Since steam will likely be present, a desiccant cartridge will be used to remove moisture from the gas before it goes on to the WGMS. The water will then circulate around a closed-loop system through a heat exchanger which interfaces the SSFF TCS. A pump will be used to maintain flow through the system, and this may cause unwanted vibrations. A second accumulator will interface this line so that waste fluids can be removed from the system.

Table 2.1-25 lists the physical components of the FDS, while Table 2.1-26 gives the resource requirements.

2.1.10 Control and Data Management System

The Control and Data Management System (CDMS) is central to the SSFF concept and will provide data collection, conversion, storage, transmission, and display, as well as providing power conditioning, conversion, distribution, and open- and closed-loop control. The SSFF CDMS is currently planned to use Space Station Data Management System (SSDMS) components as building blocks where practical. This report is a summary of work performed to define the CDMS conceptual design and the required subsystems.

Past high temperature crystal growth and directional solidification experiments relied on experiment-unique avionics packages. This requires that large funding provisions be made available for each new experiment simply to support avionics design, fabrication, and spares logistics. Obviously, this

TABLE 2.1-25. PHYSICAL COMPONENTS

Pressure	15
Temperature Sensors	7
Other Sensors	9
Valves	23
Pumps	4
Quick Disconnects	6
Accumulators	3
Desiccant Cartridge	1
Filters	1
Bottle Storage	4

TABLE 2.1-26. RESOURCE REQUIREMENTS

Power	1-2 kW
Weight	289 lb
Volume	1.5 m^3
Processing Gases	Argon Oxygen Hydrogen Helium

approach reduces the funding available for new and innovative materials processing furnaces, as well as ensuring greater schedule risk.

The objective of this CDMS study is to develop a concept for a Space Station USL avionics package that will mitigate the necessity for constant and costly unique furnace avionics design, and to do so in a manner consistent with and compatible to the SSDMS. The benefit derived from this concept will be greater funding availability for new furnace designs and will result in more advanced materials research opportunities for an equivalent financial investment.

The SSFF CDMS envisioned in this study will incorporate distributed processing ensuring that each experiment will have adequate processing capability for current and forecasted materials processing furnaces.

The SSFF CDMS will provide all data acquisition, control algorithm execution, control power conversion, and will provide for crew and SSDMS interfaces.

The SSFF CDMS concept incorporates distributed processing. Distributed processing adds fault tolerance, evolutionary growth ease and convenience, and spares logistics simplification. The use of SSDMS components is also a driver towards distributed processing in that the SSDMS component designs are biased toward a distributed system architecture (indicative of the entire SSDMS architecture). The use of SSDMS components will simplify the SSFF CDMS hardware design effort and allow the on-orbit SSFF to use common SSDMS hardware spares.

The CDMS distributed processing concept allocates one microprocessor to each furnace. This concept will ensure that the necessary control algorithms can be implemented and executed at a sampling rate sufficient for all current and anticipated needs. The distributed processing concept also allows for a furnace requiring even greater data processing capability. Should this occur, the CDMS distributed processing concept will allow for the addition of microprocessors to the system, as required, for furnace control.

The CDMS will also incorporate a three-channel 1553B local area network (LAN) to provide a data path for power control, crew interface, and downlink. The distributed processing concept is best executed on a system using a LAN. The LAN will allow convenient system expansion with minimum hardware impact. This attribute becomes desirable during initial buildup to full configuration and during future capabilities enhancements. The use of a LAN is also necessary to ensure that sufficient data path bandwidth is constantly available for closed-loop control of the furnace and prime mover power. The use of a LAN in the SSFF CDMS does not increase the amount of hardware required to implement the CDMS and prevents unnecessary resource loading of the SSDMS fiber optic 100-Mbps bus.

The CDMS will contain centrally located power conditioning equipment. The central location of power conditioning equipment addresses four issues. First, locating power conditioning equipment in the same rack as the materials processing furnace places an unnecessary restriction on the furnace mass and volume. Second, locating the power conditioning in the core rack opens the opportunity to time share the power conditioning equipment among all SSFF furnaces. By time multiplexing (load scheduling), SSFF can supply required peak furnace power with less mass and volume. Third, the thermal heat removal system can be made less complex by consolidation of the power conditioning equipment. Fourth, the power conditioning equipment is a strong source of electromagnetic interference (EMI). The furnace sensor data could be corrupted by EMI. Remote location of the power conditioning equipment will reduce this interference. Additionally, consolidation of the power conditioning equipment will reduce the number of required EMI filters, saving the associated mass and volume as well as simplifying EMI shielding design for suppression of radiated EMI.

The SSFF CDMS will be composed of the following components:

- One SSDMS Standard Data Processor
- Five SSDMS Command Multiplexer/Demultiplexers (CMDMs)
- One SSDMS Multipurpose Applications Console - Fixed (MPAC-F)
- Two Power Conditioning and Distribution Systems (PCDSs)
- One Status and Control Panel (SCP)
- Signal and power cabling within the SSFF rack assemblies.

Additional equipment interfacing with and/or supporting the CDMS includes:

- Five Environmental Control Systems (ECSs)
- Four nonsimilar unique avionics packages (supplied by the furnace manufacturer) which contain those electrical functions that are not practical to incorporate into the CDMS.
- Up to four materials processing furnaces
- The SSDMS fiber-optic communications bus
- Space Station 120 Vdc power distribution bus
- Space Station thermal heat rejection system
- The mechanical support structure.

A block diagram of the SSFF CDMS is shown in Figure 2.1-41. A typical SSFF CDMS hardware layout is shown in Figure 2.1-42.

Descriptions of the SSFF CDMS components are found in the following paragraphs.

Standard Data Processor (SDP)

This component is SSDMS equipment which will perform master control of the SSFF system. The SDP will act as a single point of contact with the SSDMS FDDI fiber-optic bus and will control data source, rates, and format for injection into the FDDI bus and subsequent downlink. The SDP will perform 1553B bus arbitration and control data flow within the SSFF. The SDP will also monitor individual CMDM and furnace performance and initiate fault alarms to the crew and ground monitoring stations.

Command Multiplexer-Demultiplexer (CMDM)

This component is SSDMS equipment consisting of an embedded data processor, expansion slots for I/O cards, a rack-mountable box, a power supply, and a menu of standard I/O cards. This component will interface directly with the materials processing furnace. The CMDM will execute all algorithms necessary to perform open- and closed-loop control of the furnace. A separate CMDM is located in the central rack to interface with and control the PCDS. The CMDM will have input/output for analog, digital, solenoid, and serial

TBS

FIGURE 2.1-41. SSFF CDMS BLOCK DIAGRAM

TBS

FIGURE 2.1-42. SSFF CDMS HARDWARE LAYOUT communication signals. Special purpose I/O cards will be designed for those electrical functions determined to be desirable in the SSFF CDMS and not supported by the SSDMS standard CMDM I/O card set.

Multipurpose Applications Console - Fixed (MPAC-F)

This component is SSDMS equipment which serves as the crew interface. The MPAC-F will support manual command and data entry and display of system status, and will generate detailed data displays to enhance SSFF operation and user friendliness. Mass data storage in fixed and removable media will also be available. Audio annunciation of emergency and anomaly conditions will be incorporated, as well as automatic callup of system diagrams for the affected function. The MPAC-F will interface with and communicate to the other SSFF components via a 1553B local bus.

SSFF Power Conditioning and Distribution System (PCDS)

This component is SSFF equipment and will transform the standard 120-Vdc Space Station power into the voltage and current levels required to support furnace operation. This SSFF component is not part of the current SSDMS. Included in this system will be a standard 120-Vdc to 28-Vdc conversion supply to support the unique avionics, furnace sensors, and furnace solenoid valves.

The PCDS will provide 120 Vdc to variable output level amplifiers to be used in heater power and prime mover control. The individual elements of the PCDS used for heater power control will consist of smart amplifiers using microcontrollers (special-purpose microprocessors designed for stand-alone operation) for mode and output level control. The use of microcontrollers in the PCDS power amplifier allows modes of operation not possible with conventional amplifiers. These capabilities include current output; voltage output; power output; waveform generation including bumpless ramping, status, and anomaly reporting; and performance monitoring. When used in the variable output current or power mode (user-selected modes), the amplifier outputs can be parallelled, increasing current drive to provide the large currents that are typically required for furnace heater low-impedance windings. This mode of operation allows SSFF to support a much larger variation in the furnace heater winding impedance while simultaneously maintaining a high power conversion efficiency. The PCDS will provide an output power switching matrix to facilitate software reconfiguration of the furnace heater amplifiers for output parallelling and for fault tolerance spares insertion.

Status and Control Panel (SCP)

This SSFF component consists of an interface panel giving CDMS operating status, providing an accessible main power shutoff for emergency and anomaly conditions, and for visual and audio annunciation of fault conditionings. The SCP will be partially controlled by the crew rack CMDM to facilitate software reconfiguration of the status signals and for monitoring crew operation.

The CDMS resource requirements are shown in Table 2.1-27.

The paragraphs below describe the SSFF CDMS technology and schedule risks.

Space Station DMS Component Definition Maturity Level

The DMS component definitions are immature and have a direct impact on the proposed SSFF CDMS configuration. SSDMS hardware specifications are currently changing or have recently changed. Specifications of current concern are:

- Software Development Workstations
  - Software Development flexibility
  - Hardware availability date
- SDP
  - Power requirements
  - Chassis form factor
  - Data transmission rate
  - Kernel software development and flexibility
  - Hardware availability date
  - Thermal cooling requirements
- CMDM
  - Power requirements
  - Number of I/O cards that can be accommodated
  - Chassis form factor
  - I/O sample rate limitations
  - Kernel software development and flexibility

TABLE 2.1-27. SSFF CDMS RESOURCE REQUIREMENTS

Power	120 Vdc and a maximum of 37 kW at assembly completion
Thermal Cooling	Up to 37 kW + TBD kW at assembly completion. Cooling by a combination of avionics air and avionics 20 °C water.
Consumables	Argon - TBD. Depends on particular materials processing experiments.
Data	FDDI - 0.18 Mbps. Data rate is variable and dependent on experiment data quantity.
Video	TBD
Processing Times	Variable - TBD. Depends on particular materials processing experiments.

- Hardware availability date
- I/O card function, accuracy, and number of channels
- Thermal cooling requirements

• MPAC-F
  - Power requirements
  - Amount and type of mass storage
  - Chassis form factor
  - Kernel software development and flexibility
  - Hardware availability date
  - Thermal cooling requirements.

The delivery dates for SSDMS hardware will have a direct impact on the delivery date of SSFF. Substantial SSDMS schedule slip could jeopardize the SSFF delivery date and the subsequent delivery of the USL.

The above hardware/software specifications are critical to the performance of SSFF. These specifications may shift enough based on current or future Space Station rescoping efforts to render the proposed SSFF system topology unworkable using DMS components. The SSFF program would then incur a substantial schedule risk and cost penalty to adapt the resulting DMS components, to design avionics to replace the lost capability, or to embark on a totally separate custom hardware development effort. The schedule risk and cost impact increases as the program matures.

<u>SSFF Requirements and USL Double Rack Capabilities</u>

The SSFF furnace power requirements, the weight and volume of the power conditioning and distribution avionics, could exceed the capabilities of the USL double rack. Specifications of current concern are:

• Core Rack Allocation for the PCDS
  - Avionics power conditioning at 2 W/in^3
  - Avionics power conditioning at 2 W/oz
  - One double rack weight allowance = 700 kg
    (assume 45% of 700 kg available for PCDS)
  - Power = (700 kg)x(45%)x(2 W/oz)x(35.24 oz/kg) = 22.2 kW
  - Volume = (22.2 kW)/(2 W/in^3)x(1 ft^3/1728 in^3) = 6.42 ft^3
    (This does not satisfy the 37 kW requirement for worst-case operation.)

- Furnace vs. Avionics (CDMS and unique avionics) competition for rack volume and mass allocation
- ECS volume and mass are driven by furnace requirements.

The weight and volume of one SDP, one MPAC-F, one CMDM, and the Core ECS are not known with precision. Therefore, the actual percentage of the Core rack resources available for power conditioning can only be estimated. The 45 percent weight PCDS factor allows for support structure, cabling, heat rejection equipment, and other avionics packages. SSDMS component volume and mass specification and SSFF rack capabilities will become drivers for furnace design.

Crew Interface Timeline Requirements

The amount of crew time required to operate the SSFF has not yet been defined. Specific guidelines need to be developed for the hardware/software/manual control breakpoints study.

Integration and Operational Cost Impacts

There is no satisfactory historical example of taking program-approved hardware qualified by JSC and incorporating it into experiment hardware to be qualified by MSFC. Current concerns are:

- Differences in factor of safety
- Differences in verification requirements
- Waiver approval cycle.

2.1.11 Modular Software

The Modular Software concept is key to the concept of providing a cost-effective and flexible SSFF. Candidates for software modules include but are not limited to: Heater Controls, Translation Mechanisms, Video and Graphics processing, Signal Processing, Command and Control, and Uplink and Downlink. The SSFF Modular Software is currently planned to use SSDMS hardware and software components as building blocks where practical. This report is a summary of work performed to define the Modular Software conceptual design and the required development and embedded resources.

Past high temperature crystal growth and directional solidification experiments relied on experiment-unique avionics packages and, therefore, unique software to support this hardware. This led to unnecessary expense where functionally equivalent but incompatible software packages have been created for each new system. Standardizing the computer hardware for all experiments served by the SSFF eliminates the need for experiment-unique software unless an experiment has a unique functional or science requirement.

The objective of this study is to identify software functions that are sufficiently general to serve a range of experiments, reducing software life-cycle costs per experiment. Further, as software modules or packages are developed, tested, and shared by what would have previously been separate programs, reliability should increase significantly. This approach should reduce the funding required for new and innovative materials processing furnaces, as well as ensure greatly reduced schedule risk.

The SSFF Modular Software envisioned in this study will incorporate software engineering practices consistent with ensuring that each experiment will have adequate processing capability for current and forecasted materials processing furnaces. Further, all software will be designed to permit future modification and cost-effective maintenance over the software and system life cycle.

The SSFF software will provide for heater controls; translation mechanisms; video/graphics; signal acquisition and processing; command and control; and uplink/downlink of data, timelines, commands, and programs.

The SSFF Modular Software concept incorporates the use of SSDMS processors, LANs, and software. Specifically, the following SSDMS Computer Software Configuration Items (CSCIs) will provide the basis for further software development: Ada Runtime Environment (RTE)/Operating System (OS), Network Operating System (NOS), Standard Services (STSV), Data Storage and Retrieval (DSAR), User Support Environment (USE), System Manager (SM), and Master Object Data Base (MODB). One more software CSCI the Operations Management Application (OMA) places requirements upon is all elements of the distributed DMS. Payloads are required to supply operational parameters to the Operations Management System (OMS) through runtime objects defined in the MODB. Detailed descriptions of the CSCIs are given in Table 2.1-28.

TABLE 2.1-28. SSFF SOFTWARE CSCI DESCRIPTIONS
(Sheet 1 of 3)

Ada Run Time Environment (RTE)/Operating System (OS)	Responsible for the ADA tasking system and interface to the processor environment, including real-time clock.
Network Operating System (NOS)	Provides for communication between processors and processes in the DMS distributed architecture.
Standard Services (STSV)	Implements the management of the Runtime Object Data Base (RODB). Runtime objects are used to track all data and controls in the distributed DMS architecture.
Data Storage and Retrieval (DSAR)	Essentially performs the function of the file manager of Disk Operating Systems. It provides for the creation, deletion, and modification of files, and maintains security of the file system.
User Support Environment (USE)	Provides for the human interaction with the DMS system through the keyboard and screen of the MPAC. USE further defines prescribed methods for the display of data and entering of commands and data.
System Manager (SM)	Monitors and controls the software resources within a processing node.
Master Object Data Base (MODB)	Provides for the definition of the RODB. This CSCI is a ground-based function, but it defines all movement of data and commands (objects) onboard the SSF.
Heater Controls	Responsible for the implementation of control algorithms such as Proportional Differential Integral (PID) controls of single effector/sensor pairs, and more complex algorithms using modern control theory which takes into account the Plant (uncoupled responses of the system) and relates these uncoupled responses in a system of equations to produce an appropriate control output.

TABLE 2.1-28. SSFF SOFTWARE CSCI DESCRIPTIONS
(Sheet 2 of 3)

Translation Mechanisms	A variety of Translation mechanisms are used in Furnace Modules. For example the Bridgman-Stockbarger furnaces use linear translation to move either the furnace or sample in relation to the other. The science requirement for mcirogravity places restriction on translation mechanisms for the amount of vibration which they can impart to a sample in processing. This can be limited through the use of microstepping stepper motors to produce sufficiently smooth motions. Rotational translation has also been identified. Along with the requirements for motion come the requirements to monitor that motion. Both absolute and relative motion must be monitored. Various methods such as linear and rotary potentiometers, shaft (optical) encoders, and linear (optical) encoders may be used.
Video/Graphics	The Science requirements have identified the need to produce and interact with imaging. Visible, Infrared, and x-ray imaging are requirements. To the DMS system, the image capture is not essential. It is assumed that all images will be converted to pixel-based arrays for manipulation by the Video/Graphics software. Pixel subtraction, edge enhancements, and other techniques may be employed to improve image quality. Pattern recognition may be used in the monitoring of crystal growth, with possible feedback into control algorithms.
Signal Acquisition and Processing	Signals in the form of accelerometer data may be monitored to characterize the ambient environment in which crystal growth occurs. Because of the vast amount of data that can be accumulated from accelerometers alone, there is a need to filter, transform, and recognize significant events as opposed to random background noise.

TABLE 2.1-28. SSFF SOFTWARE CSCI DESCRIPTIONS
(Sheet 3 of 3)

Command and Control	Commands to the SSFF may originate onboard (MPAC keyboard), or from ground-based Principal Investigators at the Payload Operations and Integration Centers (POICs). The possibility of two commands arriving simultaneously requires that there be an arbitration discipline enforced in software. Also, because of the nature of the control algorithms and the nature of the processes under control, commands must limit checked and checked for appropriateness based upon a knowledge of the timeline and history of a particular experiment.
Uplink/Downlink of Data, Timelines, Commands, and Programs	At various times, data to the ground (POIC) will change subject to a change in processing. Changes to timelines, operational data (gains in controls), and changes in software shall be accommodated through uplink from the ground. End-to-end verification of data transmission is essential to system integrity.

Where practical, SSFF software shall be coded in Ada as are most SSF DMS CSCIs. However, the SSFF CDMS system will be based in part upon the use of microcontrollers, as in the power conditioning system. Further, various signal processing and video processing functions are best performed by specific processing architectures for which no Ada compilers or RTEs exist or the existing one are not appropriate.

Table 2.1-29 lists the SSFF embedded resource requirements.

2.1.12 Video Imaging Subsystem

Based upon the video/imaging requirements for the Visibly Transparent Furnace, VCG Furnace, HWFZ Furnace, and the Interface Radiographic Measurement System, and the limited capability of the SS WP-02 DMS, it will be necessary to develop a dedicated subsystem for the acquisition, processing, compression, storage, and transmission of video/imaging data. This report covers the conceptual design of the Video Imaging Subsystem performed under the SSFF Conceptual Design Study.

The requirements identified in the SCRD specify 1028 x 1028 pixels of resolution at 12 bits per pixel and between 20 and 30 frames/sec. The SCRD also specifies capability for onboard viewing with frame rate conversions and frame grabbing capability to support image enhancement. Currently, WP-02 plans to provide the capability for image processing, including image enhancement techniques through the C&T network, which can be viewed over the monitors at the MPAC. The C&T will be limited to NTSC signals only, and, based on the access limits to the FDDI, may actually have to be compressed below NTSC resolutions. WP-02 DMS system is providing a Mass Storage Unit capable of 250 Mbytes of storage which is good for about 8 sec of data at the peak generation rate.

The Video Imaging Subsystem will be composed of the components listed in Table 2.1-30, and a block diagram of these components is given in Figure 2.1-43. The monitor, processor, control unit, and data storage unit will be located in the Core facility rack. These components will interface to standard or user-unique light sources and cameras in the Furnace Module. They will also interface to unique cameras and imagers which provide the TBD signal format. The control unit will provide the signal conditioning and formatting necessary to

TABLE 2.1-29. SSFF-EMBEDDED RESOURCE REQUIREMENTS

Processing	A combination of DMS SDP, MSU, CMDM, and MPAC processors as well as other TBD processing elements.
Data	FDDI - TBD Mbps. Data rate is variable and dependent on experiment data quantity.
Video	TBD
Processing Times	Variable - TBD. Depends on particular materials processing experiments.

TABLE 2.1-30. VIDEO IMAGING SUBSYSTEM COMPONENTS

COMPONENT	NUMBER	NOTES
Dedicated Video Processor	1	80386 processor on an open bus for user-developed cards to perform image processing
High-Resolution Monitor and Keyboard	1-3	Display and keyboard for onboard viewing. Current MPAC could be used if high-resolution monitors/high-resolution graphics cards are added to the WP-02 design
Camera Control Unit	3	The signal conditioner and shutter control for the camera head
Mass Storage Unit	3	MIL-STD-2179
Imaging Detector Device	3	Integrated into the Furnace Module
Light Source	3	Integrated into the Furnace Module

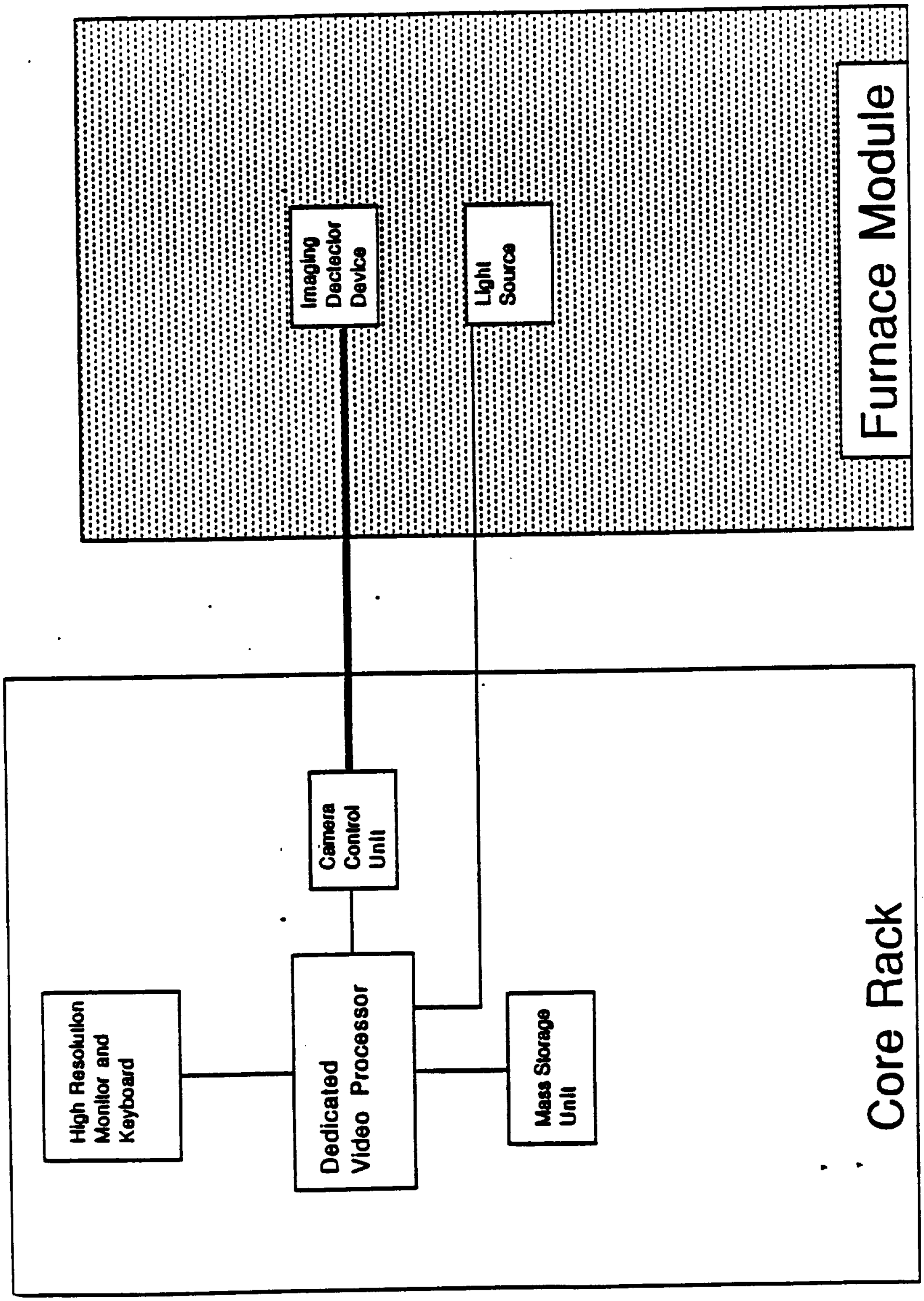


FIGURE 2.1-43. VIDEO IMAGING SUBSYSTEM

interface to the dedicated video processor. A unique imager or camera may require a unique control unit. Each interface of the control unit shall be specified to ensure the maximum flexibility to the user community.

The dedicated video processor should be a bus with public specifications driven by at least a 80386 processor with capability for unique image processing boards to be inserted. The 80386 is marginal for many image processing techniques but is planned as the primary processor for SSDMS equipment. This design will be similar to off-the-shelf boards and PCs for ground-based video systems. The development of an open-bus system is essential to ensure the ability to incorporate advanced capabilities expected to be common practice during the timeframe in which this system is flying aboard the SSF. This is a tricky issue, since many times an open standard based on convectively cooled (forced air) ground-based buses is modified to allow cooling through the sides to a coldplate. The SDP provided by WP-02 could serve as this processor if the modifications to the bus architecture were published and an interface card to the HDRL were provided. The SDP would require modification to incorporate the boards for image processing and the drivers for a high-resolution monitor. The current MPAC could be modified for use in the Video Imaging Subsystem at a lower development cost, if the bus architecture were clearly specified and public. Low-cost breadboards based on the IBM PS2 with a Multibus II augmentation and off-the-shelf Image Processing Boards could easily be developed for the MPAC design, but the modifications to the Multibus II backplane are not public. The MPAC could provide the processing and monitoring capability. Either route would require the development of a high-resolution video monitor to allow onboard viewing of the high-resolution images. There may be difficulty developing a high-resolution monitor that can be flight qualified. The dedicated processor will support the network interface to the HDRL provided by WP-02. Currently, there is no specification on this interface and no interface card identified in the PDR documentation.

The Mass Storage Unit will be required to store video data, since the WP-02 DMS will only provide one MSU with TBD Mbytes of storage. Currently, this unit is proposed as the ZOE recorder for all payloads and subsystems in the SSF USL. The Mass Storage Unit planned for the Video Imaging Subsystem will be a MIL-STD-2179 recorder with up to 1 Gbyte of storage and 250 Mbps data rate. This system is being developed for the ATMOS project and may be flight qualified; however, the technology is still not proven.

The camera/imagers will be commercially available CCDs up to 1024 x 1024 which actually have 1,028 lines but only 1,024 or 1,026 useful lines depending on the mode of operation. With the current CCD technology, high resolution is inversely proportional to the frames/sec and there may be difficulty in obtaining 30 frames/sec at 1024 x 1024, but current technology is close. Lower resolutions will permit much higher frame rates if required. Each camera provided by the SSFF as common equipment shall be compatible with the standard control unit in the Core Facility. Other cameras may require unique control units which are compatible to the standard interface of the dedicated video processor. The imager device may also be a unique device for the Interface Radiographic Measurement System requiring a unique control unit. This device has resolution comparable to the aforementioned CCDs, but the signal format has not been defined.

The Video Imaging Subsystem will require the resources defined in Table 2.1-31 for operation. These values could be significantly larger to incorporate user unique processing capabilities and imaging sources.

The Video Imaging Subsystem can be developed to meet the requirements for onboard viewing and data storage; however, downlink will be limited by access to the C&T system and the capability of TDRSS. Downlinking for telescience will not be under the control of the payload developer. Currently, the interface to the C&T network is limited by 10 Mbps access from the FDDI network and there is no interface for the DMS processors identified for use with the HDRL through the patch panel. The fiber used in the HDRL is identical to the fiber used in the FDDI LAN. While the advertised capability says that 1 Gbps is available, only 100 Mbps will be usable. The 1 Gbps is a theoretical value for the optical fiber. This same fiber is limited to 100 Mbps for the FDDI LAN.

Specific requirements for image processing and data compression may require unique user-developed cards and associated software developed by a payload developer for a specific mission or experiment. This system should employ a modular hardware and software configuration with the Orbital Replacement Unit being at the camera and board level.

TABLE 2.1-31. VIDEO SYSTEM RESOURCES

Power	250 W
Total Weight	125 lb
Volume	.03 m^3
Data	
• Resolution	1024 x 1024 pixels
• Bits per Pixel	8-12
• Frames per Second	1-30
• Max. Data Rate	252 Mbps @ 20 fps

The development of a flight-qualified, high-resolution monitor has not been done. There are many feasibility issues related to flight qualifying a high-resolution monitor. Currently, the Department of Defense has several projects to improve the technology based on processes which do not have as many safety concerns.

2.1.13 United States Materials Laboratory (USML)

USML provides the required resources to facilitate materials processing experimentation within the Common Module environment. USML consists of the following nine subsystems which are described briefly in the following paragraphs. (See Figure 2.1-44.)

- Structures/Mechanisms
- Electrical Power (EPS)
- Data Management/Communications (DMS)
- Environmental Control and Life Support (ECLSS)
- Thermal Control Subsystem (TCS)
- Software (S/W)
- Vacuum Vent
- Process Materials Management (PMMS)
- Laboratory Characterization/Support Equipment (or simply "Laboratory Support Equipment").

2.1.13.1 Structures/Mechanisms - The structures/mechanisms subsystem consists primarily of equipment racks and secondary structure required to accommodate subsystem and experiment equipment, and the necessary mechanisms to facilitate:

- Maintenance/replacement of rack-mounted equipment
- Access to module pressure shell
- On-orbit installation/removal of integrated racks.

2.1.13.2 Electrical Power System (EPS) - The EPS provides electrical power to USML subsystems and experiments. The USML-unique EPS hardware consists of Payload Power Control Units (PPCUs) and various

USML

TBS

FIGURE 2.1-44. TBS

cable assemblies. Redundant power is supplied as required to critical hardware. The current EPS design concept is illustrated in Figure 2.1-45.

2.1.13.3 Data Management and Communications System (DMS) - The USML DMS provides:

- Control of USML experiments and subsystems
- Monitoring of USML experiments and subsystems
- Interface with the SSDMS
- Caution and Warning System interface for MTL experiments and subsystems
- Experiment and subsystem data collection.

USML-unique DMS hardware includes local controllers (one per experiment rack), dedicated processors (Process Fluids, Payload Waste, Payload Support, Video) plus miscellaneous hardware.

2.1.13.4 Environmental Control and Life Support System (ECLSS) - TBS.

2.1.13.5 Thermal Control Subsystem (TCS) - TBS.

2.1.13.6 Software - USML software consists of the applications software required to execute the MTL functions via the local controllers and dedicated MTL processors. Safety significant functions of MTL S/W include:

- Caution and Warning interface with SSDMS
- Experiment control
- Malfunction detection and automated contingency control.

2.1.13.7 Vacuum Vent - The USML Vacuum Vent subsystem provides a high-quality vacuum resource (10^{-3} torr) to support experiment activities. The vacuum vent is essentially divided into two independent systems, one on each side of the module aisle. Each system consists of 15 cm (6 in. i.d.) primary vent lines with 5 cm (2 in. i.d.) secondary lines that provide vacuum access for each rack, plus the necessary isolation valves and interconnect hardware.

Note the the Vacuum Vent subsystem is intended to provide a vacuum resource only, and is not intended for overboard disposal of gaseous

EPS

DESIGN

TBS

FIGURE 2.1-45. TBS

waste products (waste disposal is accomplished via the PMMS). Because the Vacuum Vent provides a substantial diameter access to space vacuum, it is essential that adequate design features be incorporated to preclude inadvertent dumping of MTL atmosphere. (See Figure 2.1-46.)

2.1.13.8 Process Materials Management System (PMMS) - The PMMS provides two major functions: storage/resupply of process fluids and safe handling, removal, storage, and disposal of MTL payload waste products. Process fluids considered to be MTL provided include:

- Hydrogen gas
- Helium gas
- Nitrogen gas
- Argon gas
- Oxygen gas
- Carbon dioxide gas
- Freon gas
- Water.

MTL waste products come from the various experiment operations (including glovebox operations).

2.1.13.9 Laboratory Support Equipment - Laboratory Support Equipment includes those items required to support on-orbit experimental procedures and evaluation of the results. Specific items are TBS.

Vacuum Vent

TBS

FIGURE 2.1-46. TBS

3.0 SUMMARY OF RESULTS

3.1 HAZARDS

To date, the PSA has identified 39 potential SSFF hazards (29 for flight hardware, 10 for GSE), many with applicability to more than one element and/or subsystem. The hazards identified are listed in Tables 3.1-1 and 3.1-2. Element applicability and a reference to the supporting hazard report (Appendix A) are noted in the table. Hazards involving GSE, GFP, and some MTL will be identified and assessed later.

3.2 ASSESSMENT TO DATE

The assessment to date has consisted of reviewing the derived requirements shown necessary by the PSA versus available design data. In most cases, design data details available to fully assess compliance are insufficient. Therefore, an assessment of the impact of derived requirements on the design was attempted.

The majority of the inherent SSFF hazards identified can be satisfactorily controlled with design features or operational constraints with minimal impact if implemented at this point in the program. "Satisfactorily Controlled" meaning controlled to the minimum acceptable level specified by NASA in SS-SRD-0001, NHB 1700.7B, and KHB 1700.7A.

Exceptions to the above are discussed below.

3.2.1 SSFF

Many hazards associated with SSFF appear to be controllable via the identified methods (refer to Appendix A), although certain unknowns and potential problem areas continue to exist. These items are discussed below.

3.2.1.1 Containment of Hazardous Materials During Processing, Ampoule Failure, and Maintenance - TBS

3.2.1.2 Vacuum Vent Safety - TBS

3.2.1.3 Safety Accommodation Requirements - Although USML subsystems will provide a measure of design safety in support of experiment operations, it is possible that USML safety provisions will not totally mitigate a given hazard in every case. In some cases, no specific USML hazard control

TABLE 3.1-1. PRELIMINARY SSFF HAZARD LIST (Sheet 1 of 2)

(Reports contained in Appendix A)

SUBSYSTEM/HAZARD TITLE	NUMBER
FLIGHT	
Release of Hazardous Material into Habitable Area (Processing Phase)	SSFF-FLT-1
Release of Hazardous Material into Habitable Area (Pre- or Postprocessing)	SSFF-FLT-2
Hazardous Touch Temperatures	SSFF-FLT-3
Rupture of Pressure Vessel/Lines and Fittings/ Components	SSFF-FLT-4
Loss of Cooling	SSFF-FLT-5
Exposure of Crew to Frangible Materials	SSFF-FLT-6
Electrical Shock	SSFF-FLT-7
Ignition Sources	SSFF-FLT-8
Toxic Offgassing of Materials in Habitable Areas	SSFF-FLT-9
Use of Flammable Materials	SSFF-FLT-10
Structural Failure Due to Launch, Flight, and Stress Corrosion	SSFF-FLT-11
Exposure of STS or Space Station Electrical Systems to EMI	SSFF-FLT-12
Software Control of Critical Functions	SSFF-FLT-13
Inadvertent Mixing of Reactive Chemicals Leading to Exothermic Reactions, Corrosion, Toxic Offgassing	SSFF-FLT-14
Chemical Reaction in CM Venting System/Waste Stowage	SSFF-FLT-15
Personal Injury or Equipment Damage Due to Improper Handling/Operating Equipment/Procedures	SSFF-FLT-16
Inability to Vent/Clean Up	SSFF-FLT-17
TBD	SSFF-FLT-18
Loss of Power	SSFF-FLT-19
Equipment Damage Due to Improper Electrical Interface	SSFF-FLT-20

TABLE 3.1-1. PRELIMINARY SSFF HAZARD LIST (Sheet 2 of 2)

(Reports contained in Appendix A)

SUBSYSTEM/HAZARD TITLE	NUMBER
Ignition of Flammable Atmosphere	SSFF-FLT-21
Leak in Water Coolant System	SSFF-FLT-22
Release of Inerting Gas into USML	SSFF-FLT-23
Crew Overexposure to Onboard Radiation	SSFF-FLT-24
Crew Exposure to Excessive Acoustic Noise	SSFF-FLT-25
Finger Traps/Pinch Points	SSFF-FLT-26
Crew Exposure to Sharp Edges/Corners	SSFF-FLT-27
Leakage (QDs, etc.)	SSFF-FLT-28
Release of Conductive Particulates	SSFF-FLT-29
GROUND	
Rupture of Pressure Vessel/Lines/Fittings/Components	SSFF-GRND-1
Pinch Points/Entrapments (Personnel)	SSFF-GRND-2
Flammable/Ignition Sources	SSFF-GRND-3
Electrical Shock	SSFF-GRND-4
Structural Failure from Induced Loads	SSFF-GRND-5
Pressure Testing	SSFF-GRND-6
Equipment Damage Due to Improper Equipment Interface Connections	SSFF-GRND-7
Injury to Personnel and/or Equipment Damage Due to Obstructions/Tripping Hazards	SSFF-GRND-8
Inadvertent Operations of Controls Resulting in Personnel Injury/Equipment Damage	SSFF-GRND-9
Excessive Acoustical Noise (GSE)	SSFF-GRND-10

will exist because of a lack of commonality among experiments; in other cases it may be impossible or impractical to implement all hazard controls at the USML level. For this reason, safety accommodation requirements are needed to ensure that the experimenter provides a level of safety and failure tolerance sufficient to guarantee that system-level safety is consistent with program requirements.

Safety accommodation requirements should be structured to ensure an adequate level of safety without undue restriction on experiment design and activity.

3.2.1.4 Lab Equipment Development - A general safety concern associated with the lab equipment (and with USML operations in general) is that the techniques and hardware for the subject applications have evolved in the Earth laboratory environment where gravity and near-unlimited ventilation capabilities are taken for granted. It is assumed that the off-the-shelf required lab equipment will be used where possible to minimize program costs. Special attention will be required to ensure that all aspects are considered in evaluating the safe use of off-the-shelf hardware and Earth-developed laboratory techniques in the USML environment.

Areas of special concern include:

- Containment of hazardous materials
- High voltage, X-radiation and EMI associated with the magnetic suppression and other potentially high EM-field-producing equipment
- Segregation of potentially reactive products within gloveboxes
- Ignition source control
- Detection of toxic material and frangible material failures.

3.2.1.5 ECLSS Interfaces - A number of potential atmospheric contaminants generated by SSFF experiment operations are toxic. Other contaminants, although not by themselves hazardous, could interact with substances or equipment present within USML to create hazardous conditions. Severity of some of the hazards associated with USML experiment chemical usage depends on (1) detection, (2) containment, and (3) the effectiveness of the ECLSS at removing these from the habitable atmosphere. This interface will require careful evaluation to ensure compatibility.

3.2.1.6 Safety-Critical Power Source - The current EPS concept provides two redundant power sources to each experiment rack. Since the SSFF experiments are at least potentially hazardous, one of the following measures will be required to ensure experiment safety in the event of failure of both power buses (i.e., to maintain the required two-failure tolerance):

- The experiment hardware will, via passive measures, have to revert to a safe state upon loss of input power.
- Backup batteries could be employed for experiments requiring power to achieve safe status. However, the batteries would potentially induce additional hazards.
- A third power source could be added. This approach has proved successful on Spacelab.

3.2.1.7 Segregation of Waste Products - USML waste management provisions allow removal of only a few preapproved, "acceptable" wastes and subsequent purge of the removal system itself. USML does not provide the capability for waste removal or segregation beyond this. The overall scheme of hazard control, therefore, will have to use procedural controls such as materials restrictions, operational timelining, periodic purge of waste removal provisions, etc., to ensure incompatible or mutually reactive materials are not vented or brought together. This concern is of particular significance, also, to the use of gloveboxes. Enforcement will presumably occur via safety accommodation requirements (see para. 3.2.1.3).

3.3 RECOMMENDED ADDITIONAL STUDIES

In the process of doing the PSA, specific areas were identified where additional studies may be warranted, as follows:

- Areas where the required hazard control measures are not within the state of the art or are limited by the state of the art
- Areas where previous NASA decisions have driven the current baseline to a point where the risks may not be acceptable given the hazards identified in the PSA.

Areas meeting the above criteria are listed and discussed in Table 3.3-1.

3.4 FUTURE EFFORT

This PSA will be continued throughout the conceptual phase as necessary to affect design, operations, and requirements development. Results will be documented and maintained so they can be transitioned to the PDR/Phase 0/I analysis (an essential aspect of the PSA). Concerns, open items, and recommendations that result from the continuing PSA effort will be forwarded to NASA, as necessary.

TABLE 3.3-1. RECOMMENDED ADDITIONAL STUDIES

PROPOSED STUDY	RATIONALE
Coolant System Designs	Cooling, heat rejection systems using water or air should be studied to assess the impacts and design options available to ensure control of hazards resulting from loss of cooling to avionics systems and furnaces; use of QDs; maintenance activities; furnace runaway overpowering the cooling system; and leaks into the habitable volume of USML/SS.
Effect of Not Being Able to Vent Toxic Gases and/or Dump Same into Waste Storage	Alternative approaches should be studied such as a dedicated SSFF waste storage medium to handle possible sample leaks or failures which otherwise would prevent cleanup and/or repairs on-orbit; or constraint sample selection to the very least toxic elements.
Sample Failure Detection Schemes/Devices	This proposed study is seen as a must if SSFF is to operate as planned and crew access and maintenance are to be performed. Science development of failure detection methods is currently being pursued for the CGF project. Other, more expensive, and massive methods/equipment are also available, such as mass spectrometers, etc., and will have to be traded off.

APPENDIX A

SPACE STATION FURNACE FACILITY HAZARD REPORTS

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Release of Hazardous Material into Habitable Area (Processing Phase)

NO. SSFF-FLT-1

PAGE 1 **OF** 3

DATE June 1, 1990

HAZARD DESCRIPTION: Contamination of USML and/or Space Station, damage to sensitive components, and possibly severe injury to crew and possible long-term illness.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT X 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Ampoule/Cartridges • Experiment Apparatus Container (EAC)	1. Failure (leakage, etc.) of containment provisions of sample material 2. Leak of containment vessel	1., 2 Multiple, redundantly sealed containers (two or three depending on the hazard level) shall be used to contain potentially hazardous materials.	NSTS 1700.7B, para. 209.1
		1:, 2 A positive means of leak detection and/or containment failure detection shall be provided.	Derived

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SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-1

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Ampoule • EAC	See 1.	Pressure Vessels (general comments)	Note 1: Pressure vessel may satisfy the initial requirement of containment but they may pose several problems: 1. Costs to qualify and maintain 2. Frequent crew access may be prohibitive in qualifying for long term SS use, where seals may be subjected to repeated cycling and risk of damage during opening/ closings. 3. Will have to show materials compatibility during processing phases. 4. Component replacement or damage may require vessel to be requalified - cannot do on-station. Note 2: Possible high pressure operations and/or failures (e.g., MASA Rapid Quench System) may drive some facilities to a pressure vessel containment design.
• Furnace Core insulation materials	2. Damage to furnace insulation results in generation of toxic dust/fumes	2. Specific controls may include one or more of the following: • Mechanism to hold the cores securely during launch (separate containers then assemble on-orbit may be the safest(?) • Control heatup rates and maximum temperatures to within core specification limits	Note 2: Use of toxic BeO cores poses some possible risks.

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-1

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Furnace Core insulation materials (Conc.)			1. There are two potential ways of generating dust: • Thermal shock: - Higher than specification temperatures - Extreme heatup rates - Hot cores suddenly cooled - coolant water leaks into furnace • Vibration/shock - During launch loads - Breaking during handling The SMAC (temporary) for a 7-day SL mission is .0004 mg/m^3. Although this is very low, it could be more severe for SS use. CGF experience should help in better understanding the potential hazards associated with BeO and controlling them. An unknown may be the possible effect of prolonged high temperatures and repeated cycling of heatup/cooldown on the cores during extended Space Station use.

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Release of Hazardous Material into Habitable Area (Pre- or Post-Processing Phase)

NO. SSFF-FLT-2

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DATE June 1, 1990

HAZARD DESCRIPTION: Contamination of USML and/or Space Station, damage to sensitive components, and possibly severe injury to crew and possible long-term illness.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Ampoule/Cartridges • EAC • Furnace Core Insulation	1. Failure/leak of sample containment	1.a. A positive means of failure/leak detection shall be provided.	Derived
		1.b. When the interior containment provision status cannot be positively determined prior to planned crew access, crew access will be denied or a backup containment scheme will be utilized to allow crew access without exposing themselves or contaminating the USML/SS.	Derived
		1.c. Processing samples will be nonhazardous/nontoxic at ambient conditions	
	2. Post-processing "cold" failure of ampoule due to containment apparatus structural weakening during the processing phase or a pre-existing flaw.	2. Sample ampoules processed at high temperatures and/or for extended periods of time shall be handled via glovebox or protected in some other means from failure and contaminating USML/SS.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Hazardous Touch Temperatures

NO. SSFF-FLT-3

PAGE 1 **OF** 2

DATE June 1, 1990

HAZARD DESCRIPTION: Contact with high temperature (or cold temperature) surfaces greater than 45 °C can cause possible injury to crew.

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Avionics Boxes • Furnace Outer Containment Surfaces • Ampoule/Cartridges • Scientific Support Equipment	1. Exposure to high temperature surfaces	1.a. Ampoule/cartridges shall be allowed to adequately cool prior to access by the crew.	Derived
		1.b. Surfaces having high touch temperatures (>45 °C) and potential access by the crew shall have warning labels and be protected.	NASA-STD-3000, para. 6.5.3
	2. Exposure to low temperature surfaces (e.g., cryogenic systems)	2. Equipment having a cold surface temperature (<4 °C) and accessible to the crew shall have warning labels and be protected.	NASA-STD-3000, para. 6.5.8.
	3. Retrieval of instruments, contact with interior surfaces	3. Provisions shall be made to preclude contact with furnace surfaces and equipment with a temperature greater than 45 °C (113 °F).	Derived
	4. Viewport material overheating due to impinging furnace operation	4. Viewport cover/covers shall be designed such that viewport assemblies/materials do not exceed 45 °C (113 °F).	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-3

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	5. High surface temperatures due to internal heat production	5. Where equipment cannot be insulated, guards, shields, and placarding shall be used as a means of precluding contact.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Rupture of Pressure Vessel/Lines and Fittings/Components

NO. SSFF-FLT-4

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DATE June 1, 1990

HAZARD DESCRIPTION: Rupture of pressure vessel or components results in fragments impacting personnel, USML-1/SS, potential loss of habitable atmosphere, or release of water or gases into USML-1/SS.

HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF ____ 3. HWFZ ____ 4. MASA ____ 5. VTF ____ 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
High Pressure Consumable Storage Volumes	1. Defect in design 2. Insufficient structural design or pressure system component failures	1.,2. ...pressurized storage containers shall be located so that explosive failure of the container will not produce a critical failure of the SSPE.	SS-SRD-0001B, Sec. 3.0, para. 2.1.11.2.4.1 and 2.1.11.2.4.2
		Pressure vessel and components designed to MIL-STD-1522A and NSTS 1700.B requirements	NSTS 1700.7B, para. 206, 208.4, 208.5
	3. Failed-on heaters	3. Two-failure tolerance against failing on a heater(s) capable of overheating pressurized components shall be provided.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Loss of Cooling

NO. SSFF-FLT-5

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DATE June 1, 1990

HAZARD DESCRIPTION: Loss of cooling causes overheating of furnaces, containment apparatus, avionics boxes resulting in fire, toxic offgassing, explosion, and possible severe injury to crew.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Furnaces • EACs • Avionics	1. Loss of coolant flow during high temperature operations (air flow or water flow)	1.a. Design shall be fail safe or 2 FT to loss of cooling 1.b. The design shall preclude propagation of failures from payload to the environment outside the payload.	Derived (See JA-061) NSTS 1700.7B, para. 206

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Exposure of Crew to Frangible Materials

NO. SSFF-FLT-6

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DATE June 1, 1990

HAZARD DESCRIPTION: Contact with eyes or ingestion of broken glass due to rupture/breakage of the ampoule assembly, camera lens, etc., results in possible severe crew injury.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
• Sample Ampoule/Cartridges • EAC • Observation Viewports • Camera Lenses	1. Thermal shock 1.a. High internal pressures 1.b. Thermal degradation 1.c. Careless handling	1.a-b: Design shall preclude propagation failures from the payload to the environment outside the payload. 1.c. All frangible items shall be contained to prevent release of glass/quartz particles. <u>Options</u>: (1) Detection method that would detect broken glass/quartz particles (2) Glovebox <u>Note</u>: Quartz ampoules should be enclosed in some type of container during stowage and/or handling/ transfer operations (i.e., plastic sheath, etc.)	NSTS 1700.7B, para. 200, 206, 209 Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Electrical Shock

NO. SSFF-FLT-7

PAGE 1 **OF** 2

DATE June 1, 1990

HAZARD DESCRIPTION: Electrical shock could result from contact with voltages in excess of 30 V.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Avionics and Cabling Hardware Portable electrical measuring devices, lap top computers, other similar devices	1. Defective components (wires, insulation, cabling, etc.) coupled with inadequate bonding/grounding	1. Bonding and grounding will be accomplished in accordance with MIL-B-5087B	NSTS 1700.7B, para. 206, 213
	2. Exposed terminals or high voltage sources accessible to the crew	2.a. Bleeddown circuitry will be provided for HV capacitors.	Derived
		2.b. High voltage sources will be inaccessible to the crew.	Derived
	3. Internal shorting of portable electric equipment	3. Portable electrical equipment shall be designed such that an internal short circuit will not result in a voltage potential being applied to the core or enclosure.	Derived
	4. Crew contact with electrical connectors during maintenance operations.	4. Only female connectors shall be used as sources of power.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-7

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	5. Shorting of rack-mounted equipment to encasement	5. Electrical panels, controls, etc., accessible to personnel shall be maintained at ground potential at all times equipment is powered.	Derived
	6. Crew contact with exposed electrical cables, buses, etc.	6. Cabling shall be routed, restrained, etc., to prevent its inadvertent use as a hand-hold.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Ignition Sources (Electrical)

NO. SSFF-FLT-8

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DATE June 1, 1990

HAZARD DESCRIPTION: Overheating of electrical wiring results in ignition of flammable materials.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Avionics and Cabling	1. Wiring/fusing size improper to protect downstream wiring from overheating in the event of a short or partial short circuit	1. Wiring/cabling will be designed in accordance with SLP 2104, to the first circuit protection device within the instrument and the instrument protected internally in accordance with MIL-HDBK-978A (NASA).	NSTS 1700.7B, para. 206, 213

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Toxic Offgassing Materials in Habitable Areas

NO. SSFF-FLT-9

HAZARD DESCRIPTION: Toxic offgassing causes temporary or permanent crew injury/illness.

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HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Facility	1. Use of materials which offgas toxic gases or other toxic byproducts	1.a. SSFF assemblies will be offgas tested in accordance with NHB 8060.1B. 1.b. Hardware will be built in conformance with approved material lists. 1.c. Material will be selected in accordance with MSFC-HB-527F/JSC 09604F. An MUA will be submitted for all material having less than an "A" or "K" rating as defined in MSFC-HB-527F/JSC 09604F.	NSTS 1700.7B, para. 209.3

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Use of Flammable Materials

NO. SSFF-FLT-10
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DATE June 1, 1990

HAZARD DESCRIPTION: Fire and smoke causes severe injury/illness to crew and damage or malfunction of equipment.

HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ___

OPERATIONAL PHASE 1. **GROUND** ___ 2. **ASCENT** ___ 3. **ON-ORBIT** X 4. **DESCENT** ___

SSFF MAJOR ELEMENT 1. **AADSF** X 2. **CGF** X 3. **HWFZ** X 4. **MASA** X 5. **VTF** X 6. **FURNACE CORE** X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Avionics Systems and SSFF Modules	1. Use of flammable materials in proximity to an ignition source results in fire in habitable area.	1.a. Equipment/hardware will be built in accordance with approved materials lists.	NSTS 1700.7B, para. 209.2
		1.b. Materials will be selected in accordance with MSFC-HDBK-527F/ JSC 09604F.	
		1.c. Space Station materials requirements are specified in JSC 30233.	SS-SRD-0001B, Sec. 3.0, para. 2.1.11.3

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Structural Failure Due to Launch, Flight, and Stress Corrosion

NO. SSFF-FLT-11

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DATE June 1, 1990

HAZARD DESCRIPTION: Failure of payload structural elements or attachment hardware results in unrestrained objects in USML module which could impact Orbiter or other payloads.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT X 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Avionics Core, Furnace Modules	1. Structural elements or payload equipment lack structural strength to withstand launch or on-orbit environments (including depressurization/ repressurization) or fail due to pre-existing flaws.	1. Safety-critical structures design will be based on worst-case mission-induced loads with no negative margins of safety and ...appropriate safety factors....	NSTS 1700.7B, para. 208.1, 208.2, 208.3
	2. Use of structural materials which are susceptible to stress corrosion cracking.	2. Materials will be selected in accordance with MSFC-SPEC-522.	Derived
	3. Structural elements improperly manufactured or manufactured using unacceptable materials.	3. Safety-critical structures will be built in accordance with approved design drawings and parts lists.	SS-SRD-0001, Sec. 3.0, para. 2.2.1

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Exposure of STS or Space Station Electrical Systems to EMI

NO. SSFF-FLT-12

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DATE June 1, 1990

HAZARD DESCRIPTION: SSFF-generated EMI in excess of allowable limits interferes with Orbiter or Space Station operations.

HAZARD LEVEL: CATASTROPHIC ___ CRITICAL X

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Avionics, SSFF Magnetic Field System	1. Radiated or conducted EMI from SSFF elements caused by electrical switching and/or equipment operation	1.a. The SSFF will be unpowered during ascent. 1.b. Electronic equipment and racks (ORU, FSE, and OSE) shall meet the requirements of JSC 30237 and JSC 30238.	NSTS 1700.7B, para. 206, 212.2 SS-SRD-0001, Sec. 3.0, para. 2.1.3.4.2

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Software Control of Critical Functions

NO. SSFF-FLT-13

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HAZARD DESCRIPTION: Single software processor control of a critical safety function fails resulting in no action taken to notify crew and/or preclude hazardous event which the software was controlling; or performing the opposite function from its programmed safing function (i.e., opening instead of closing a valve).

HAZARD LEVEL: CATASTROPHIC X CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF ____ 3. HWFZ ____ 4. MASA ____ 5. VTF ____ 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Central SSFF Processor	1. EMI 2. Software flaw	1.,2. Potentially catastrophic hazards must be controlled in a two-failure tolerant manner. One of the methods for controlling the hazard must be independent of the computer system. Note: A computer system is considered zero-fault tolerant in controlling a hazard.	NSTS 1700.7B, para. 201.1e(1) and (2) Note: Effect of this requirement will drive one of the following: (1) Redundant processors (2) Expensive, time consuming S/W safety analysis, and in the end possibly still inconclusive results. (3) Removing S/W from the hazard control loop.

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Inadvertent Mixing of Reactive Chemicals Leading to Exothermic Reactions, Corrosion, Toxic Offgassing

NO. SSFF-FLT-14

PAGE 1 **OF** 2

DATE June 1, 1990

HAZARD DESCRIPTION: Reactive or otherwise incompatible materials inadvertently mix or come into contact resulting in unforeseen or undesired reaction. Possible explosion/release of heat. Possible formation of toxic byproducts, fire, corrosion, etc.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF ___ 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Gloveboxes	1. Use of incompatible materials within glovebox.	1.a. Experiment procedures excluding the simultaneous presence of mutually reactive materials within glovebox shall be utilized.	Derived - TBD safety accommodation requirements.
		1.b. Capability shall be provided for segregation of glovebox wastes, as determined by analysis.	Derived
	2. Use or generation of toxic products within glovebox.	2.a. Same as 1.a. above.	Derived
		2.b. Negative pressure differential (with respect to module) shall be provided to preclude release of glovebox atmosphere into habitable atmosphere.	

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-14

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	3. Use or generation of flammable products within glovebox	3.a. Same as 1.a. above.	
		3.b. Design shall preclude glovebox lighting (and other internal electrical components) from serving as a credible flammable atmosphere ignition source.	Derived
		3.c. An inert atmosphere shall be utilized in glovebox to preclude combustion.	Derived
	4. Experiment hardware fault or procedural error.	4. Experiment testing or analysis shall be accomplished to demonstrate appropriate level of hardware safety.	Derived - Safety Accommodation Requirements are TBD
	5. Sample materials	5.a. A comprehensive analysis of candidate sample materials compatibility during all processing and use phases including failure which could release materials causing inadvertent mixing, fume, and/or gas formation shall be performed.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Toxic Material Release in USML Venting System/Waste Storage

NO. SSFF-FLT-15

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DATE June 1, 1990

HAZARD DESCRIPTION: Toxic material released into the USML venting system resulting in vent system failure, contamination of Space Station outer envelope, and possible crew injury, module/equipment damage.

HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT. ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Furnace Modules	1. Sample containment failure releasing potentially toxic/hazardous material into the containment vessel.	1. Venting of toxic materials through the vacuum vent system is prohibited.	TBS
	2. Sample containment failure releasing potentially toxic/hazardous material into the containment vessel.	2. Release of toxic materials into the USML Waste Management System is prohibited.	TBS

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Personal Injury or Equipment Damage Due to Improper Handling/Operating Equipment/ Procedures

NO. SSFF-FLT-16

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DATE June 1, 1990

HAZARD DESCRIPTION: Inadequate provisions and procedures (including laboratory) for handling of program hardware results in unforeseen and/or uncontrolled motion, operation, or contamination. Possible impact or other adverse interaction with surrounding equipment/facilities causing major equipment damage. Possible severe personnel injury.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Equipment	1. Exceedance of realistic human capabilities results in damage to equipment, possible injury to personnel during handling/ operations procedures.	1.a. Develop detailed operational scenarios for SSFF; identify specific operations for which human capability could be a major factor. Incorporate capability critical operations into verification testing program.	Derived
		1.b. Verify that no one-person operation requires more than two hands to accomplish; consider any requirements for use of hands to stabilize and positioning/tethering that might be required. Verify any questionable operations in a mockup environment.	Derived
		1.c. Verify that planned operations can be readily accomplished under lighting conditions that will prevail during the actual operation. Identify and implement additional or auxiliary lighting as required.	NASA STD 3000 to be used as a guideline; derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-16

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	2. Electric shock resulting from personnel exposure to energized electrical components during assembly, checkout, maintenance, or reconfiguration.	2.a. Design shall allow removal of power from equipment packages, electrical connectors, etc., prior to maintenance activities.	
		2.b. Female electrical connectors only shall be used to supply downstream power.	Derived
		2.c. Supply power shall be removed prior to removal or maintenance of electrical assemblies.	Derived
		2.d. Electrical connectors shall be deenergized prior to mate/demate operations.	Derived
	3. Inadvertent activation or tripping of switches or controls and initiating potentially hazardous event(s), through error or translation/travel over or on control panel(s).	3. Sensitive/emergency switches/ controls shall be physically protected from inadvertent activation by the use of guards, covers, or other suitable means and shall be clearly marked, visible, and remain accessible to the crew.	Derived
	4. Use of experimental procedures and equipment developed for the Earth laboratory environment results in contamination of/damage to SSFF/USML or surrounding equipment.	4. Perform additional study to evaluate standard scientific laboratory procedures; identify areas where standard procedures are: a. Unsuitable for the anticipated USML environment. b. Unprecedented in previous manned flight use.	Note: Identify and implement alternative procedures or equipment as required.

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Inability to Vent/Clean Up

NO. SSFF-FLT-17

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DATE June 1, 1990

HAZARD DESCRIPTION: Inability to vent or clean up following contamination, accident, etc., could result in possible equipment damage, injury to crew, loss, or degradation of habitable living conditions of the affected area.

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Furnace Modules	1. Failure of sample container releases toxic materials, glass particles inside of containment vessels	1.a. Because of the prohibition to venting toxic material, containment must be fail safe to both venting and release of contaminants into USML.	Derived
		1.b. No cleanup of module will be attempted by crew. Note: Possible options to 1.b. above: • Vent into a module dedicated waste storage medium • Vent overboard through a filter trap • Jettison (not very realistic) • Bring module back home (tough decision!)	Derived
	2. Free floating contaminants in habitable volumes.	2. Portable hand-held vacuum systems shall be provided to remove dusts, ablative particles, and other particulate contaminants in habitable areas.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: TBD

NO. SSFF-FLT-18

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HAZARD DESCRIPTION:

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT ____ 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF ____ 3. HWFZ ____ 4. MASA ____ 5. VTF ____ 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	TBD	TBD	TBD

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Loss of Power

NO. SSFF-FLT-19

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DATE June 1, 1990

HAZARD DESCRIPTION: TBD

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT ____ 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF ____ 3. HWFZ ____ 4. MASA ____ 5. VTF ____ 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Incoming Power to SSFF	TBD	TBD	TBD

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Equipment Damage Due to Improper Electrical Interface

NO. SSFF-FLT-20

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HAZARD DESCRIPTION: Misconnection and damage to cable connectors leading to power and signal mismatch with subsequent arcing and surges/equipment damage.

HAZARD LEVEL: CATASTROPHIC ___ CRITICAL X

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Power and Signal Connectors	1. Connectors having same shell size located side by side	1. The design of SSFF shall conform to the "Space Station Design Criteria Document JSC 30213."	JSC 30000, Sec. 3, para. 2.1.13, Rev. B
	2. Mating connectors while energized creating arcs and power surges	2. Same as above	Same as above
	3. GSE (or FSE) used for checkout exceeds equipment input capabilities.	3. Same as above	Same as above

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Ignition of Flammable Atmosphere

NO. SSFF-FLT-21

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DATE June 1, 1990

HAZARD DESCRIPTION: Ignition of flammable atmosphere resulting in fire/explosion leading to possible loss of life, mission.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Furnace Modules/Core Stowage Cabinets Gloveboxes Handtools	1. Use of flammables in SSFF systems, i.e.: - Reagents - Solvents (cleaning) - Flammable gas by-products of processing	1. Flammable cleaning/chemical agents shall be prohibited	Derived
		1.a. Potentially explosive containers....	SS-SRD-0001, Sec. 3, para. 2.1.11.2.4.1, Rev. B - Note: requirement is being studied for possible revision.
		1.b. Provisions shall be made to prevent hazardous accumulations of fluids....	SS-SRD-0001, Sec. 3, para. 2.1.11.2.5, Rev. B
		1.c. The Space Station materials requirements....	SS-SRD-0001, Sec. 3, para. 2.1.11.3, Rev. B
		1.d. Drains, vents, and exhaust ports from creating hazards....	SS-SRD-0001, Sec. 3, para. 2.1.11.2.6, Rev. B
		1.e Hazardous gas detectors shall be provided in locations where release of a hazardous gas would pose a hazard.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-21

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	2. Electrical arcing of relay contacts/switches.	2. Where hazardous gases may pose a potential combustion or explosive threat, electrical equipment shall be designed to explosion-proof standards or "intrinsically safe" standards.	Derived (coexperimenters could drive such a requirement on SSFF)
	3. Light sources, automated cutting/polishing equipment, etc.	3.a. Glovebox atmosphere shall not support combustion.	Derived
		3.b. Electrical equipment used within glovebox shall not serve as an ignition source.	Derived
			Derived
	4. Sparks caused by metal-to-metal contact.	4. Handtools shall be spark proof.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Leak in Water Coolant System

NO. SSFF-FLT-22

HAZARD DESCRIPTION: Failure of thermal subsystems allowing coolant to escape with subsequent degradation of system performance and USML/SS environment.

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DATE June 1, 1990

HAZARD LEVEL: **CATASTROPHIC** ____ **CRITICAL** X

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Water Cooling System	1. Internal pressure exceeds strength capability	1.a. Factors of Safety...	SS-SRD-0001, Sec. 3, para. 2.2.1.2.4.2
		1.b. Pressure vessels, pressurized lines and fittings.	NHB 1700.7A, para. 208-4, 208-5
	2. Freezing	2. No single failure shall result in freezing of water coolant.	Derived
	3. Electromechanical failures (pump, control circuits, etc.)	3. No single electromechanical failure shall result in a release of water coolant.	Derived
	4. Operator errors (Maintenance)	4. Isolation of ORUs shall be provided to ensure "Dry" maintenance changeout capabilities.	Derived
	5. Failure of nonwelded connectors or components	5. Keeping in mind requirements for maintainability, the use of welded or brazed connections shall be maximized. Where welded connections cannot be used, redundant seals shall be provided.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-22

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	6. Mechanical component failures	6. Leak detection, isolation and control...(Existing)	JSC 30000, Sec. 3, para. 2.2.12.2.2.2, Rev. B Recommend that all pressurized SSFF elements conform to MIL-STD-1522A

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Release of Inert Gas into USML

NO. SSFF-FLT-23

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DATE June 1, 1990

HAZARD DESCRIPTION: Release of inert gases (i.e., nitrogen, argon) may pose an asphyxiation hazard to crew with possibly severe consequences, and/or increase pressures inside SSFF modules/ USML.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Furnace Modules Gas Supply Storage and Plumbing	1. Opening of containment vessels	1.a. Source of inert gas shall have a manual shutoff valve between storage bottle and Furnace Module.	Derived
		1.b. Inert gases shall be purged from module(s) prior to crew entry.	Derived
	2. Leak of containment vessels	2.a. Leak detection capability shall be provided for inert gases used.	Derived
		2.b. Seals of containment vessels shall be 2 ft to leaking.	Derived
	3. Leak of storage bottles and/or plumbing	3.a. Pressure vessels, lines and fittings...	NSTS 1700.7B, para. 208
		3.b. Pressure vessels...	SS-SRD-0001, Sec. 3.0, para.
		3.c. Leak detection capability shall be provided for inert gases used.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-23

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
		3.d. The volumetric quantity available for the system to leak shall be limited to that volume which will not over-pressure or pose an asphyxiant hazard in the module.	Derived
		3.e. No two regulator component failures shall result in hazardous release of high pressure inert gas into USML.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Crew Overexposure to Onboard Radiation

NO. SSFF-FLT-24

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Use of radioactive isotopes in USML/SSFF equipment results in crew exposure to excessive radiation levels resulting in possible long-term injury/illness.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT ____ 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Proposed Use of Radioactive Isotopes Note 1: See reporting requirements for radioactive sources in NSTS 1700.7B and JSC 13830. Note 2: Accumulative radioactive dose to crew is a critical issue for extended crew missions.	1. Crew exposed to unsafe levels of radiation	1. Design shall incorporate the appropriate shielding, safety interlocks, etc., to preclude human exposure radiation levels in excess of TBD.	Derived
	2. Crew exposed to unsafe levels of radiation (operator error, inadequate shielding)	2. Radioactive units shall incorporate adequate shielding, safety interlocks, etc., to prevent crew exposure to levels of radiation in excess of TBD.	Derived
	3. Inadequate shielding results in excessive radioactive emissions.	3. CRTs shall comply with FCC regulations for radioactive emissions.	Derived Note: Portable monitoring device would allow periodic checkout of radiation levels.
		4. Quantities of radioactive sources shall be no greater than TBD.	Derived
		5. Disposal of radioactive sources shall be in accordance with TBD.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Crew Exposure to Excessive Acoustic Noise

NO. SSFF-FLT-25
PAGE 1 **OF** 1
DATE June 1, 1990

HAZARD DESCRIPTION: Excessive acoustic noise levels resulting from operation of USML subsystem or experiment equipment results in long-term degradation of crew auditory capabilities. Possible additional hazards due to failure to hear critical communications, confusion of equipment noise with C&W annunciations, etc.

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Systems	1. Excessive noise levels originating with experimenter-provided apparatus.	1. Acoustic output of experiment-provided equipment shall not exceed the levels specified in MSFC-STD-512A.	TBD Safety Accommodation Requirements
	2. Acoustic noise, audio outputs, etc., produced by SSFF sources becomes confused with onboard C&W annunciation tones.	2. Audio tones or similar output produced by SSFF sources shall be readily distinguishable from annunciation tones used by C&W.	Derived. Need to establish and advertise C&W tones to be used.

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Finger Traps/Pinch Points

NO. SSFF-FLT-26

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Space Station mechanisms and assemblies may entangle crewmen and their clothing during operational and nonoperational operating modes.

HAZARD LEVEL: CATASTROPHIC ___ CRITICAL X

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Hardware	1. Entanglement in internal mechanisms (pumps, fans, hatches, rotary equipment).	1. All mechanisms to which crewmen are exposed shall have guards and shields to prevent entanglement, or be inaccessible during operation.	Derived
	2. Levers, cranks and controls on rack facings and panels.	2. Rack facia mechanical equipment shall be minimized or positioned such that they will neither cause injury to personnel nor be damaged by snagging clothing.	Derived
	3. Grasping of blind access areas for restraint.	3.a. Blind access areas shall provide finger/hand clearances or be constructed in such a manner to preclude any pinching or trapping of the hands and fingers.	Derived
		3.b. All hand grasp areas shall be labeled.	Derived
	4. Securing pins in handrails backing out to impinge on handhold areas.	4. Positive means for securing pins shall retain them so that the pins will not back out to impinge on handhold areas.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-26

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	5. "Scissoring" action between vertically locked racks and rotated racks.	5. Handles and locking mechanisms shall be used to preclude personnel injury/damage to equipment resulting from inadvertent and uncontrolled rack movement.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Crew Exposure to Sharp Edges/Corners

NO. SSFF-FLT-27

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DATE June 1, 1990

HAZARD DESCRIPTION: Crew exposure to sharp edges/corners could result in injury to crewmembers during IVA activities. NOTE: Exterior sharp edges are addressed in PSA EVA-1.

HAZARD LEVEL: CATASTROPHIC ___ CRITICAL X

OPERATIONAL PHASE 1. GROUND ___ 2. ASCENT ___ 3. ON-ORBIT X 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
All accessible SSFF hardware items	1. Sharp edges and/or corners and protrusions 2. Crew maintenance in areas not placed under sharp edges control	1. All external and internal equipment and structural surfaces including covers, doors, removable panels, and containers accessible by the crew shall be free of sharp edges and corners for protection of personnel and equipment.	Derived
	2. Crew maintenance in areas not placed under sharp edge control	2. Same as above	

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Leakage (QDs, etc.)

NO. SSFF-FLT-28

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DATE June 1, 1990

HAZARD DESCRIPTION: Leakage from connectors, quick disconnects, etc., could cause contamination of flight hardware, habitable areas of SS, STS Orbiter, and, in severe cases, create a hazardous/flammable atmosphere leading to potential severe personnel injury and loss of mission.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ____

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT X 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Utility Plumbing	1. Leakage of connector interface due to contamination	1. All connectors and fittings required to be disconnected during flight operations shall have caps, plugs, or covers to protect the system from contamination or damage when disconnected.	Derived
	2. Mismating of connectors	2.a. System connectors shall be keyed or sized so that it is physically impossible to connect an incompatible commodity or pressure level/vessel.	Derived
		2.b. Color coding of pressure vessels, pipes, tubing and connectors shall conform to TBD upon delivery of articles.	Derived
	3. Leakage of connectors after mating due to poor design, damaged or failed parts, etc.	3.a. All liquid and gas systems shall be designed to permit leak testing after installation.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-FLT-28

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
		3.b. An isolation shutoff valve shall be installed in each system supplied from a common liquid or gas pressure source.	Derived
		3.c. Use the appropriate factors of Safety defined in Table 2-3...	JSC 30000, Sec. 3, para. 2.2.1.2.4.2, Rev. B
		4. All materials including seals, gaskets and lubricants used in flight equipment shall be compatible with the system commodity.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Release of Conductive Particulates

NO. SSFF-FLT-29

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DATE June 1, 1990

HAZARD DESCRIPTION:

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND ____ 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Systems	Failure of containment provisions during or post-processing releases fine conductive ash/dust into USML/SS.	1.a. Multiple, redundantly sealed containers (two or three depending on the hazard level) shall be used to contain potentially hazardous materials.	NSTS 1700.7B, para. 209.1
		1.b. A positive means of leak detection and/or containment failure detection shall be provided.	Derived
		1.c. Use of readily conductive process - sample materials shall be prohibited where practical.	Derived

PRELIMINARY SSFF HAZARD LIST (GROUND OPERATIONS)

SUBSYSTEM/HAZARD TITLE	NUMBER
GROUND	
Rupture of Pressure Vessel/Lines/Fittings/Components	SSFF-GRND-1
Pinch Points/Entrapments (Personnel)	SSFF-GRND-2
Flammable/Ignition Sources	SSFF-GRND-3
Electrical Shock	SSFF-GRND-4
Structural Failure from Induced Loads	SSFF-GRND-5
Pressure Testing	SSFF-GRND-6
Equipment Damage Due to Improper Equipment Interface Connections	SSFF-GRND-7
Injury to Personnel and/or Equipment Damage Due to Obstructions/Tripping Hazards	SSFF-GRND-8
Inadvertent Operations of Controls Resulting in Personnel Injury/Equipment Damage	SSFF-GRND-9
Excessive Acoustical Noise (GSE)	SSFF-GRND-10

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Rupture of Pressure Vessel/Lines/Fittings/Components

NO. SSFF-GRND-1

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DATE June 1, 1990

HAZARD DESCRIPTION: Possible severe injury to personnel, flight hardware, and ground equipment.

HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ____

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ____ 3. ON-ORBIT X 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF ____ 2. CGF ____ 3. HWFZ ____ 4. MASA ____ 5. VTF ____ 6. FURNACE CORE ____

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
Gas Supply Systems GSE	1. Pressure vessels rupture and/or burst from pressure regulator failure.	1. Pressure vessels should be equipped with relief device and designed for maximum working pressure conforming to ASME boiler and pressure vessel code.	KHB 1700.7A, para. 4.3.3.1.3 A and F(2)
	2. Internal lines and fittings rupture from over-pressurization caused by regulator failure.	2. Components should be designed to operate at the maximum system pressure or equipped with relief valve.	KHB 1700.7A, para. 4.3.3.1.3 E
	3. Service lines rupture from overpressurization caused by upstream component failure.	3. Service lines should be designed with a burst pressure equal to or greater than four times maximum operating pressure.	KHB 1700.7A 4.3.3.1.5 C
	4. Service lines/hose rupture/ separate at connectors due to stress, strain, and vibration.	4.a. Hoses should be supported and restrained.	KHB 1700.7A, para. 4.3.3.1.5 B&D
		4.b. Cooling unit should have provisions for attaching restraining devices.	KHB 1700.7A, para. 4.3.3.1.3 M

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-GRND-1

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	5. Rupture of test set lines or components due to high pressure output from failed or misadjusted pressure regulator.	5.a. Test set design should incorporate relief valves downstream from each regulator set to relieve at 10% above maximum operating pressure of succeeding stages. Relief valves should be sized for full capability flow of preceding stage in a failed mode.	KHB 1700.7A, para. 4.3.3.1.3 E,F,H,& C
		5.b. Components should be designed to withstand pressure at least four times maximum working pressure without rupture/burst.	KHB 1700.7A, para. 4.3.3.1.3 C
	6. Service hose rupture caused by high pressure from upstream component failure.	6. Hoses should be designed to withstand pressure at least four times maximum working pressure without rupture or burst.	KHB 1700.7A, para. 4.3.3.1.5 C
	7. Service hose/lines rupture or break at couplings (ends) caused by stress and strain.	7. Design of test set should provide for hose/line restraints at connections where pressure exceeds 150 psi.	KHB 1700.7A, para. 4.3.3.1.3 M
	8. Tanks rupture and leaks caused by excessive pressure or structural failures.	8. Pressure vessels should conform to ASME boiler code for hazardous chemicals.	KHB 1700.7A, para. 4.3.3.1.3 A
	9. Internal lines rupture/burst from excessive pressure or leak from fittings/couplings.	9. Lines and fittings should be designed to withstand pressures at least four times maximum working pressure without rupture or burst.	KHB 1700.7A, para. 4.3.3.1.3 C

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Pinch Points/Entrapments (Personnel)

NO. SSFF-GRND-2

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DATE June 1, 1990

HAZARD DESCRIPTION: Personnel or equipment entrapment causing injury and/or damage.

HAZARD LEVEL: **CATASTROPHIC** ____ **CRITICAL** X

OPERATIONAL PHASE **1. GROUND** X **2. ASCENT** ____ **3. ON-ORBIT** ____ **4. DESCENT** ____

SSFF MAJOR ELEMENT **1. AADSF** X **2. CGF** X **3. HWFZ** X **4. MASA** X **5. VTF** X **6. FURNACE CORE** X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Hardware and GSE items	1. Fingers/hands/arms entrapped in positioning arm structure.	1. Design should avoid or provide guarding for pinch points subject to personnel contact.	Derived
	2. Fingers/hands/arms entrapped between simulators and flight article.	2.a. Design should provide visual or mechanical/electrical means to verify gauge to test article proximity/clearance.	Derived
		2.b. Control system should be equipped with an emergency stop switch.	Derived
	3. Personnel entrapment during rotation of unit(s)	3. Provide rotating axis locks/safety pins.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Flammable/Ignition Sources

NO. SSFF-GRND-3

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DATE June 1, 1990

HAZARD DESCRIPTION: Flammable materials subject to ignition during transport, handling, and servicing. Fire or explosion with injury to personnel and destruction of flight equipment and facilities.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Materials Sample Materials Insulation Solvents	1. Static buildup and discharge on contact by service lines.	1. Design should include grounding lugs, straps, etc.	Derived
	2. Inadvertent mixing with oxidizers and other propellants.	2. Connections should be designed to preclude mixing.	Derived
	3. Leaking fluids/vapors contact with (rust) or other incompatibles.	3. All components including structures should be constructed of compatible material that is not subject to oxidation.	Derived
	4. Flammable materials come in contact with ignition sources during ground handling/testing activities.	4. Use of flammable materials shall be kept to a minimum...	KHB 1700.7A, para. 4.3.9

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Electrical Shock

NO. SSFF-GRND-4

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DATE June 1, 1990

HAZARD DESCRIPTION: Personnel injury from contact with electrically energized components.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Electrical Components EGSE	1. Personnel contact with electrically energized enclosure.	1. Design should provide positive grounding through power source cable.	KHB 1700.7A, para. 4.3.2.1 E, and 4.3.2.2 B,C, & D
	2. Static buildup due to fluid flow contact/discharge.	2. Design should incorporate grounding lugs for grounding to flight article.	KHB 1700.7A, para. 4.3.2.1 E and 4.3.2.2 B,D
	3. Short circuit in components energizes enclosures.	3. Provide grounding for enclosures.	KHB 1700.7A, para. 4.3.2.1 E
	4. Personnel contact energized component during maintenance and adjustment.	4.a. Provide guarding and warnings for exposed conductors.	KHB 1700.7A, para. 4.3.2.1 D
		4.b. Provide electrical interlocks, where necessary.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Structural Failure from Induced Loads

NO. SSFF-GRND-5

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DATE June 1, 1990

HAZARD DESCRIPTION: Handling sling/fixture bends, breaks, and/or collapses causing dropping of flight hardware and possible severe injury to personnel.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Hardware GSE (Platforms, Stands, etc.)	1. Failure of structural members from overstress.	1.a. Structural design factors shall be based on the type of material used, the type of loads, and intended use. A minimum safety factor of 3:1 applied to yield shall be used for support stands; 4:1 applied to ultimate for workstands.	KHB 1700.7A, para. 4.5.1.1 F & G
		1.b. Load limits shall be conspicuously displayed.	Derived
	2. Weld separation due to stress corrosion.	2. Critical welds should be identified on design documentation and NDI inspected.	Derived
	3. Mechanical fastener separation due to stress and vibration.	3. Tensile strength and torque valves for critical joint fasteners should be specified on design documentation.	Derived
	4. Shifting loads cause separation at joining sections.	4. Design should incorporate positive locking mechanisms to secure platform sections together and at supporting interfaces.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-GRND-5

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	5. Loading exceeding capacity	5.a. Weight handling limits must be indicated on item.	KHB 1700.7A, para. 4.5.1.1 C
		5.b. Proof-loading diagrams and weights should be indicated on design documentation.	Derived
		5.c. All pieces/parts combinations should be proof-load tested and maintained as an integral unit, i.e., rack handling sling and adapter = 1 unit, slings and shackles = 1 unit.	KHB 1700.7A, para. 4.5.1.2 A and F
	6. Weld separation from stress corrosion	6. All critical welds should be identified on drawings and NDI inspected.	KHB 1700.7A, para. 4.5.1.1 D

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Pressure Testing

NO. SSFF-GRND-6

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DATE June 1, 1990

HAZARD DESCRIPTION: Test pressures exceeding design limits of unit under test may cause ruptures and/or bursts of flight equipment and injury of personnel from flying debris.

HAZARD LEVEL: **CATASTROPHIC** X **CRITICAL** ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Flight Hardware GSE: Leak Test Sets Cooling Units Service Units Vacuum Pumps	1. Inadvertent misadjustment of pressure outputs	1.a. Controls for critical functions should be designed and located in a manner not susceptible to inadvertent operation.	Derived
		1.b. Control stations should be designed to conform to MIL-STD-1472, Chapter 5.	Derived
	2. Failures in pressure regulators	2. Relief valves should be installed in GSE output stages and sized for protection of test unit.	KHB 1700.7A, para. 4.3.3.1.3 E
	3. Connection to wrong input/output ports.	3. Service line connectors shall be selected to make it physically impossible to mate wrong connectors.	KHB 1700.7A, para. 4.3.3.1.2 D

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

CONTINUATION SHEET SSFF-GRND-6

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
	4. Structural or component damage caused by excessive depressurization	4. Design should incorporate provisions for ambient automatic pressure valves.	KHB 1700.7A, para. 4.3.3.3
	5. Structural or component damage (shock stress) from rapid recompression.	5. Design should incorporate controls for gradual recompression under normal and failed conditions.	KHB 1700.7A, para. 4.3.3.2.5
	6. Corrosion and shedding of test set components.	6.a. All materials should be checked for compatibility with service media and environment.	KHB 1700.7A, para. 4.3.9 E, F, G, and H
		6.b. Design should include filters at closest point of interface to unit under test.	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Equipment Damage Due to Improper Equipment Interface Connections

NO. SSFF-GRND-7

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Different outputs, multiple output ports/connectors, etc., permit inadvertent connection to wrong port/connector causing overpressurization, contamination, equipment damage, etc., with catastrophic results.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE ___

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Flight Hardware GSE Test Equipment	1. Cross-connecting/mismating high pressure lines to low pressure ports 2. Cross-connecting/mismating service lines with incompatible media or functions	1., 2. Service lines should be designed (keyed or sized) to preclude inadvertent mismating.	KHB 1700.7A, para. 4.3.3.1.2 D
	3. Crossed or switched connections during test setup	3. Design should incorporate keying or sizing of connectors to preclude mismatch.	KHB 1700.7A, para. 4.3.2.1 A

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Injury to Personnel and/or Equipment Damage Due to Obstructions/Tripping Hazards

NO. SSFF-GRND-8

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Personnel working around equipment tripping or falling over obstacles (power cables or hoses, etc.) causing injury to personnel and damage to equipment.

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ____ 3. ON-ORBIT ____ 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Flight Hardware GSE	1. Personnel tripping over power cables	1. Design should provide protection for cables and personnel.	KHB 1700.7A, para. 4.3.2.1 F
	2. Personnel tripping over hoses/service lines	2. Service lines should be supported and restrained in a manner not creating a hazard.	KHB 1700.7A, para. 4.3.3.1.3 R
	3. Personnel tripping over protruding framework at base of stand	3. Mark protrusions of less than 12 in. elevation from floor with physical hazard colors (black and yellow stripes).	Derived

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Inadvertent Operation of Controls Resulting in Personnel Injury/Equipment Damage

NO. SSFF-GRND-9

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Opening/closing valves, switches, etc., by mistake or wrong sequence. Possible damage to equipment and injury to personnel.

HAZARD LEVEL: CATASTROPHIC X CRITICAL ___

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ___ 3. ON-ORBIT ___ 4. DESCENT ___

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Flight Hardware GSE	1. Personnel operating wrong valve/switch out of sequence or in wrong direction	1.a. All valves and controls should conform in shape, size, and mode of operation as outlined in NASA-STD-3000.	Derived
		1.b. Controls for operations should have positive feedback to control panel to indicate function/event is initiated or occurring.	KHB 1700.7A, para. 4.3.3.1.3 S

SPACE STATION FURNACE FACILITY PRELIMINARY SAFETY ANALYSIS

HAZARD TITLE: Excessive Acoustical Noise (GSE)

NO. SSFF-GRND-10

PAGE 1 **OF** 1

DATE June 1, 1990

HAZARD DESCRIPTION: Powered ground support equipment generating noise levels exceeding 75 dBA.

HAZARD LEVEL: CATASTROPHIC ____ CRITICAL X

OPERATIONAL PHASE 1. GROUND X 2. ASCENT ____ 3. ON-ORBIT ____ 4. DESCENT ____

SSFF MAJOR ELEMENT 1. AADSF X 2. CGF X 3. HWFZ X 4. MASA X 5. VTF X 6. FURNACE CORE X

SUBSYSTEM/ITEM	HAZARD EVENT/CAUSE	CONTROL REQUIREMENTS	REFERENCE
SSFF Flight Hardware GSE	1. Electrically driven motors/pumps	1. Equipment should be selected and/or designed to produce the minimum sound pressure levels under normal loads and environment. NOTE: OSHA requires engineering principles be exhausted prior to requiring hearing protection.	KHB 1700.7A, para. 4.2.1.2

APPENDIX B

LARGE BORE BRIDGMAN FURNACE
AND
HIGH-PRESSURE FURNACE
STUDY

INTRODUCTION

The purpose of this report is to summarize the findings of the study being performed to determine the impact on the Space Station Furnace Facility (SSFF) of accommodating a Large Bore Bridgman (LBB) Furnace and a High-Pressure Furnace (HPF). This report is part of a research study entitled "Space Station Furnace Facility," and the analyses and investigations presented are intended to fulfill paragraphs 3.4 and 3.5 of the statement of work.

The work was done by the Teledyne Brown Engineering Advanced Programs Division, through Marshall Space Flight Center, for the National Aeronautics and Space Administration.

OBJECTIVE

The LBB provides the capability for controlled directional solidification experiments on large diameter samples. The HPF is intended for processing in environments at pressures up to 100 atmospheres.

CONCEPTUAL DESIGN

The Furnace Module consists of a furnace with a hot zone, an adiabatic layer, and a cold zone. The furnaces are installed within environmental canisters for containment of toxic vapors. The furnace operating environment will be inert with a pressure of up to 2 atmospheres. A negative pressure difference between the canister and the lab environment must be maintained. Both furnaces will have a bore of approximately 8 cm in diameter. The hot zone of the LBB will be approximately 60 cm long to accommodate a 55-cm long sample, and the hot zone of the HPF will be approximately 30 cm long to accommodate a 25-cm long sample. There will be several independently controlled heaters in the hot zones, including booster heaters. During directional solidification, the LBB will utilize furnace translation rather than sample translation to minimize induced accelerations to the sample. A schematic of the complete LBB system in the SSFF is shown in Figure 1.

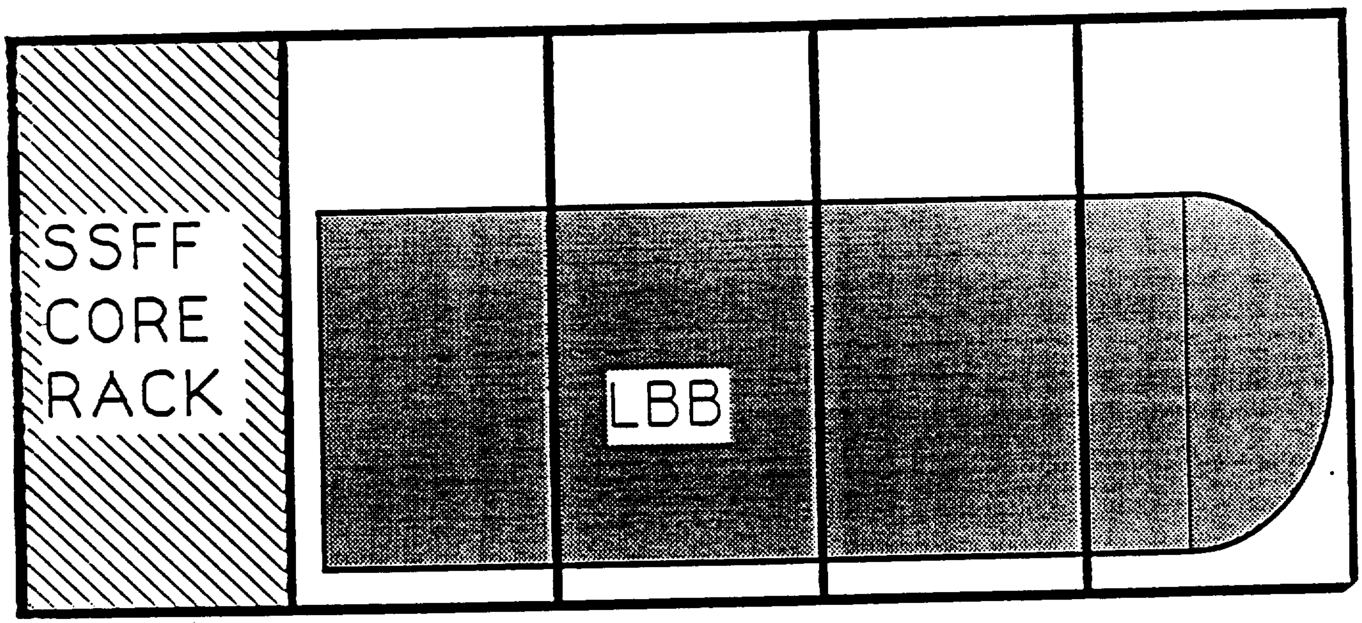


FIGURE 1. LARGE BORE BRIDGMAN CONCEPT

RESOURCE REQUIREMENTS

Rough estimates of the resource requirements of the LBB and HPF were derived from the most recent available data on similar smaller scale materials processing furnaces and from information contained in the Microgravity and Materials Processing Facility (MMPF) data base. These values were compared to those of the Crystal Growth Facility (CGF) and are presented in Table 1. The values indicate that the LBB and HPF are drivers of power, thermal cooling, venting, consumables, mass, and volume. The data requirements are not impacted much since the motor control of the furnaces defines this requirement and will probably be the same for all three furnace modules.

TABLE 1. LARGE BORE BRIDGMAN AND HIGH-PRESSURE FURNACE IMPACTS

	LBB	HPF	CGF
Mass of Furnace and Canister (kg)	3500	1635	187.6
Height of Canister (cm)	396	180	165.3
Diameter of Canister (cm)	150	75	66.1
Maximum Power (W)	25000	25000	2100
Thermal Requirement (W) (Nominal)	15000	15000	1000
Purge Gas Volume, liters (STP)	7200	1050	4.449

CRITICAL ISSUES

Some of the numerous critical issues associated with accommodating the LBB and HPF modules are as follows:

- The magnitudes of the stored energy in these Furnace Modules are a potential safety hazard.
- Since it is anticipated that the SSFF will have to provide the gases for the inert atmospheres of the furnace canisters, the volumes of gas required are critical.
- The exhaust gases of the modules must also be stored in the SSFF since venting may be restricted because of toxicity.
- The power and thermal requirements are values which are expected to be accommodated far into the future of Space Station development.
- The mass and volume requirements preclude the use of standard rack mounting.

APPENDIX C

AMPOULE, SAMPLE EXCHANGE, AND TRANSLATION MECHANISMS STUDY

INTRODUCTION

Teledyne Brown Engineering has begun work on the conceptual design of the Space Station Furnace Facility (SSFF). The SSFF is a multiuser facility capable of supporting a wide variety of experimentation in solidification physics and crystal growth. The preliminary definition of this facility has defined a variety of unique Furnace Modules which can be integrated into a common support system and structure for mission-particular experimentation. A contract for the conceptual design of this common support system and structure was awarded to TBE with Authority To Proceed given on June 2, 1989, and the contract was signed on August 31, 1989. The contract specified many trade studies to be performed in support of the conceptual design effort. On September 11, 1989, a Science Requirements Workshop was held to review the progress and priority of the work being performed with the science community. After a review of the tasks listed in the contract statement of work, the trade studies concerning the ampoule mounting, translation mechanisms, and sample exchange (paragraphs 5.5.3, 5.5.4, and 5.5.5, respectively) were considered by the science community to be of low priority and dependent on the designs of the unique Furnace Modules. Because of the immaturity of many of the Furnace Module designs, it was decided to minimize the effort for these analyses.

This report is a summary of the work performed under the following tasks:

5.5.3 Hot Ampoule Exchange

- Must sample cool before exchange
- Does sample cool in facility or in separate sample holder

5.5.4 Ampoule Mounting

- Position accuracy
- Support one or both ends of ampoule
- Is rotation capability required
- Thermocouple interface
- Universal holder versus several specialized

5.5.5 Translation Mechanism

- Ampoule loading
- Ampoule translation
- Sample differential translation (float zone)

To adequately complete these trade studies, specific information pertaining to furnace module designs is required. This level of detail may not be available until a furnace module nears a Critical Design Review (CDR) completion. More detailed assessments of these issues should be performed as the furnace modules reach the preliminary and critical phases of design.

5.5.3 Hot Ampoule Exchange

A trade study on the benefits and merits of hot ampoule exchange was performed. The issue is whether the ampoule should be allowed to cool in the furnace core or removed hot and allowed to cool in a separate facility. Hot ampoule removal has the potential advantage of reducing sample processing time by the sum of the sample-furnace core cooldown time and the furnace core heatup time. The advantages and disadvantages of each technique are listed below.

Exchange Hot Ampoule

Advantages

- Processing time savings
- Furnace is not thermally cycled during each ampoule change

Disadvantages

- Burn hazard exists with manual exchange
- Ampoule breakage toxicity hazard in cases where sample materials are toxic at high vapor pressures
- If an ampoule exchange carousel is used, the hot ampoule will radiate to other ampoules in the carousel
- A separate ampoule cooling canister may be necessary because of the above issue
- Added experimental parameter due to the unknown cooling rate

Cool Ampoule Before Exchange

Advantages	Disadvantages
• Eliminates burn hazard • Reduced risk of hot ampoule breakage	• Lost processing time

For the case of electronic materials processing (crystal growth), the sample exchange time compared to the sample processing time is small; therefore, it is felt that the small amount of time saved does not warrant the increased risks and complexity of hot ampoule exchange. However, in the case of metals and alloys experiments, the relatively short processing time (4 to 8 hours) may warrant the addition of a hot ampoule exchange system. In cases where higher cooling rates than allowed by the core heat loss rate are required by the experiment, a separate sample holder-container may be required. Cooling of the hot ampoule in a separate holder is investigated in the next study. A hot ampoule exchange design concept is also illustrated.

<u>Cool in Furnace Core or Separate Holder</u>

A trade study was performed to determine the benefits and difficulties involved in incorporating a separate sample container to allow out-of-furnace ampoule cooling. Such a system may be required on short-duration experiments or in cases where sample cooling rate may be an important experimental parameter. The advantages and disadvantages of each system are listed below.

Cool Sample in Separate Sample Container

Advantages	Disadvantages
• Offers an additional level of containment in case of an ampoule rupture during cooldown • Isolates the hot ampoule from the rest of the system and other ampoules	• More complex system; greater cost • Difficult to adapt to existing furnace concepts such as CGF. The addition of a container to the existing design would lengthen the furnace by ~30 in. • Thermocouple/sensor outputs from the ampoule may be more difficult to configure

Cool Sample in Furnace Core

Advantages	Disadvantages
• Simplified design; lower cost • Lower rack space requirement	• Requires more processing time per sample • Fixed cooling rate

In cases where the experiment run time is short or where cooling rates may be higher than allowed by the furnace core, it may be necessary to incorporate a separate cooling canister. Ampoules could be loaded into the furnace core by an exchange arm and then unloaded back into a cooling canister. This concept is not easily adapted to any of the baseline furnace configurations and would require further study. A design concept for such a system is illustrated in Figure I. The addition of a load-unload ampoule container to the CGF carousel would require increasing the length of the furnace core and would place it outside the boundaries allowed by the rack space (Figure II).

5.5.4 Ampoule Mounting-Universal Holder Versus Several Specialized Holders

The SSFF contract identifies the issue of utilizing a universal ampoule holder. The advantages and disadvantages of universal and specialized holders are listed below.

Universal Ampoule Holder

Advantages	Disadvantages
• Common holder design; possible cost savings • Easier to design into an automatic ampoule exchange system	• Sensor output limited by common connection constraints • Material compatibility - difficult to design for when ampoule material may be an unknown • Limitation on thermocouple types

It would be advantageous to incorporate a universal ampoule holder or fixture into the furnace design. The design could be configured such that each ampoule utilized an adapter flange which incorporated any of the ampoule unique features required. A design concept is illustrated in Figure III.

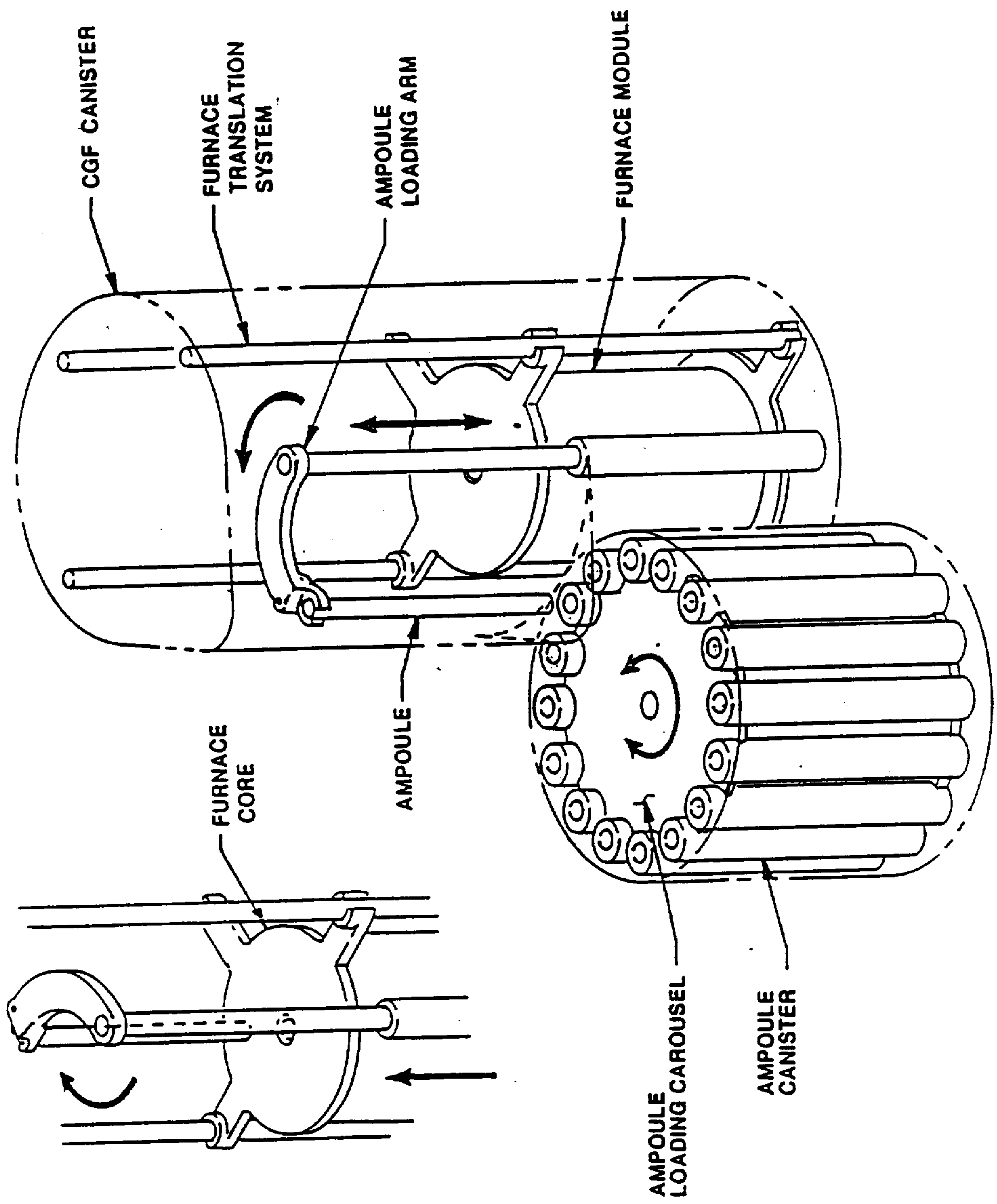


FIGURE I. SAMPLE EXCHANGE CONCEPT

FIGURE II. TBS

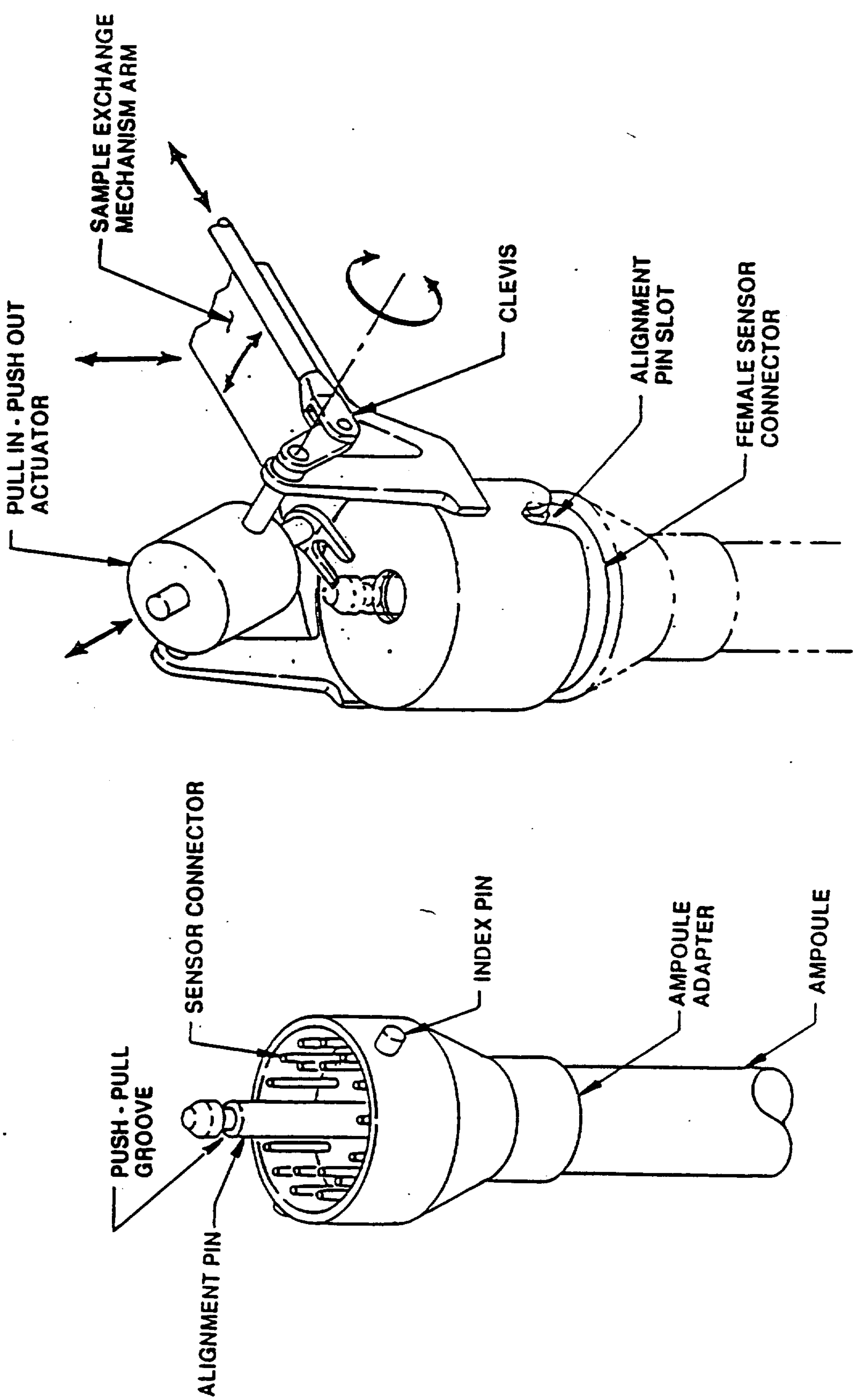


FIGURE III. AMPOULE ADAPTER CONCEPT

This feature would make it much easier to incorporate an automated sample exchange system into the furnace design. However, because of the immaturity of the furnace module design concepts, it is recommended that this issue be set aside for further study.

Support One or Both Ends of Ampoule

A trade study was performed to determine the advantages of supporting the sample ampoule on both ends as opposed to one end only. The advantages and disadvantages of both configurations are listed below.

Support Ampoule on One End

Advantages

- Reduced heat loss out the end of the ampoule
- Furnace core may be closed on one end; reduced heat losses
- Reduced sample end effect on hot zone side
- Easier to accommodate ampoule thermal expansion

Disadvantages

- Less rigid ampoule mounting
- Ampoule alignment may be more difficult

Support Ampoule on Both Ends

Advantages

- Increased rigidity
- During ground-based tests the lower support reduces any potential problems with ampoule creep and failures at elevated temperatures
- Aids in ampoule alignment

Disadvantages

- Axial thermal expansion of the ampoule must be accommodated
- Increased heat load-ends effects
- A longer ampoule may be required
- Requires the furnace core to be open at both ends
- To accommodate a multiple exchange system, the ampoule must be loaded through the furnace core on the lower support

Sample support on one end only offers several advantages over a two-support system and is preferred. Figure IV shows a conceptual design for a

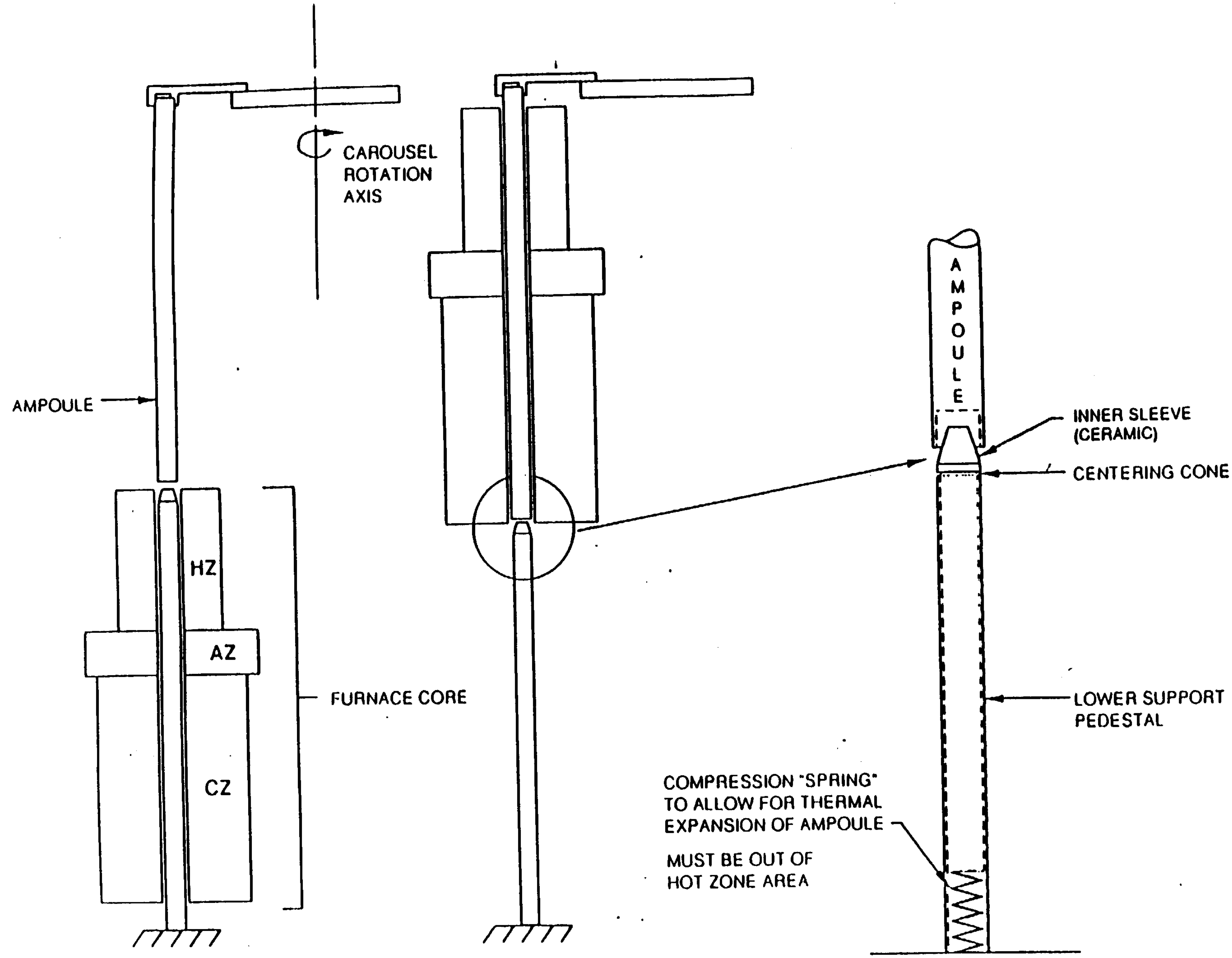


FIGURE IV. AMPOULE ATTACHMENTS TRADES

two-support system. The greater simplicity of a single support negates any potential advantages of increased rigidity.

Positioning Accuracy

The contract specifies an ampoule position accuracy of ±0.1 cm with a resolution of 0.01 cm. It is not clear whether these numbers reflect axial and radial accuracy or concentricity with the furnace bore. Ampoule position and/or position measurement accuracy is a function of:

- The straightness of the ampoule
- Angular misalignment in the sample holder
- The positioning accuracy of the sample exchange mechanism
- The accuracy of positioning the sample in the ampoule
- The location of the ampoule position with respect to a reference point on the furnace core is controlled by the thermal expansion characteristics of the ampoule and the furnace structure
- Position measurement accuracy with respect to a reference point on the furnace core is controlled by the resolution and accuracy of the position sensor - LVDT, Linear Potentiometer, optical encoder, etc.

Because of the equipment-specific nature of this issue, it is recommended that the issue be deferred to the furnace core manufacturer.

Is Rotation Capability Required

The issue of ampoule end rotation appears to be experiment specific. It is felt that the issue be deferred until experiment requirements are better developed.

Sample Differential Translation (Float Zone)

No float zone furnaces are identified in the candidate baseline.

Thermocouple Interface

This study addresses the location of the ampoule thermocouple lead wire termination point and how the TC lead wire connection is made.

Considerations involved with this issue are:

- Automated or manual sample exchange
- Accommodation of a variety of thermocouple types
- Lead wire length
- Ampoule mounting.

The feature of automatic or manual exchange is required by the contract. If the ampoule is designed to be loaded and unloaded automatically by an exchange mechanism, then each ampoule must have a common end configuration or adapter to allow it to be coupled to the exchange arm. The thermocouple connection point should be integral with the ampoule coupler. The TC-sensor connection plug should be designed to allow for both automated coupling and manual coupling. The contract guidelines and assumptions statement require that the design allow for six to eight thermocouples per sample. Utilizing only one thermocouple type would require 16 thermocouple connection points per ampoule. If the ampoule exchange arm connector is designed to allow for 3 thermocouple types, 48 thermocouple connection points are required.

The connection point might either be a pin-type connector or a series of radial "pads" around the exchange mechanism adapter on the end of the ampoule. Due to the equipment-specific nature of this study, it is recommended that the final decision be deferred to the furnace core manufacturer.

5.5.5 Translation Mechanism

Common Translation System

The furnace translation system may be either furnace-core unique or common with the rack. The advantages and disadvantages of each system are listed below.

Common Translation Mechanism

Advantages	Disadvantages
• Lower cost; common components	• It may be very difficult to design a translation system to accommodate the wide variety of furnace configurations, shapes, and lengths
• The drive components may be better isolated from the furnace environment	• The furnace core design would be driven by the translation rack space requirements
• The translation rates required may be accommodated by a common system	• For the case of furnace translation it will be more difficult to maintain atmospheric integrity of the furnace core (Bellows may be required)
	• This configuration requires a more modular furnace design and possibly more setup time

Translation Mechanism Integral with Furnace Core

Advantages	Disadvantages
• The entire furnace apparatus is contained in a single enclosure as in CGF, AADSF, and MASA.	• Potentially higher cost
• Reduced setup time upon experiment changeout	
• Similar to existing designs	
• The furnace core design is not driven by the need to couple to a common translation rack	

The use of a common translation system has many potential problems which may be difficult to solve. Therefore, it is recommended that the use of a common translation system be abandoned in favor of the use of common translation system components such as motors and drive screws. The translation system for each furnace core could be designed from a catalogue of common flight-certified components. This inventory of flight-certified components would be developed and maintained by the SSFF Project.

Ampoule Translation Versus Furnace Translation

Directional solidification requires controlled relative motion between the furnace and the sample during processing. The goal is to minimize acceleration imposed on the sample by the translation mechanism or changes in translation velocity. The SSFF contract requires a maximum g level of 10^{-4}. To achieve the required relative motion, either the furnace or ampoule must be translated. The advantages and disadvantages of each technique are listed below.

Furnace Translation

Advantages

- Minimize the acceleration imposed on the sample by the translation mechanism - the sample sees no accelerations from speed changes (other than drive train vibration)
- Easier to accommodate a multiple sample exchange mechanism. The exchange system must be integral with the translation system in a sample translation configuration.

Disadvantages

- Requires more rack space; two complete furnace core volumes are required
- Furnace translation requires a higher torque capacity drive system

Sample Translation

Advantages

- Cables associated with power, cooling, sensors, etc., are not required to move
- It is possibly easier to have a common translation system with this configuration

Disadvantages

- More exposure to drive system vibration and acceleration

Furnace translation is preferred because of the g-level requirement of the contract. Furnace translation reduces the magnitude of acceleration disturbances imposed on the sample by drive system noise and translation rate changes.

<u>Ampoule Loading</u>

The contract states that the furnace be capable of both manual and automated ampoule loading. This requirement is closely tied with the requirements of section 5.5.3 in the contract and cannot be treated as an independent issue. Several ampoule loading schemes can be envisioned.

- Direct loading by hand into the ampoule-holding fixture
- Automatic loading by a carousel
- Automatic loading by an exchange arm from an ampoule carousel canister (Figure I)
- Automatic loading by a fully articulated robotic system

Design issues:

- Does the loading mechanism interfere with the ampoule being manually loaded?
- Will the automatic loading device be capable of meeting the ampoule alignment requirements or will a separate alignment mechanism be required?
- Does the design allow for hot ampoule exchange?
- How are thermocouple lead wires and sensor wires routed through the exchange mechanism?
- Does the loading mechanism allow for variation in ampoule lengths?
- How will the exchange mechanism - ampoule holder be protected from heat conduction up the ampoule?
- If the ampoule is loaded from a separate container, does the ampoule storage container share a common vacuum and backfill system with the furnace?
- Are motion points or mechanical joints in the exchange mechanism designed to be self-locking or do they require active control to maintain a given position?

SSFF-PSA-001
June 1990

APPENDIX D

FURNACE POINTING SYSTEM STUDY

INTRODUCTION

The purposes of this study are to determine the feasibility and develop a concept for a furnace pointing system. This system will be part of the Space Station Furnace Facility (SSFF).

This system will be used to align the furnace axis parallel to the residual gravity vector on the space station. The residual gravity vector is composed of the air drag component and the gravity-gradient component. Other acceleration inducing steady-state disturbances such as light pressure are considered to be several orders of magnitude less. The gravity-gradient force is produced by the radial variation in the force of gravity about the space station center of mass. An object will only experience a zero gravity gradient if it is positioned along the flight path of the space station's center of mass. The current configuration for the Space Station Freedom (SSF) will place the U.S. lab module approximately 12 m from the space station Center of Mass (CM). This displacement will impose an Earth-directed component of 3×10^{-6} g (~.1μg per meter) and a CM-directed component along the truss axis of 1×10^{-6} g on the furnace module (worst-case assumptions based on the current configuration). The magnitude and direction of the gravity-gradient components are considered to be constant in the study as the center of mass position of the space station will be considered to be unchanging.

The air drag force is produced by atmospheric drag at the orbital altitude. This component is cyclic in nature and varies at approximately two cycles per orbit. The magnitude of the air drag component varies significantly with atmospheric conditions and is a function of solar flux, diurnal bulge, orbital altitude, time of year, and projected area of the space station. This study will consider two cases: where the air drag is of the same magnitude as the gravity gradient (maximum of 3×10^{-6} g) and where the maximum air drag is one order of magnitude less than the gravity gradient. The scenario in which both components are of the same order of magnitude represents a worst-case orientation.

OBJECTIVE

The pointing system will be required to maintain a preferred alignment (based on the particular science requirements of the experiment) with the residual gravity vector. The benefits of both an active and passive alignment system will be weighted. This study must also determine any disturbances induced on the furnace module by the pointing system. The sense and magnitude of the gravity vector and the preferred orientation will be determined and controlled by an accelerometer subsystem. The system must be capable of accommodating a variety of furnace module shapes and allow on-orbit module interchangeability.

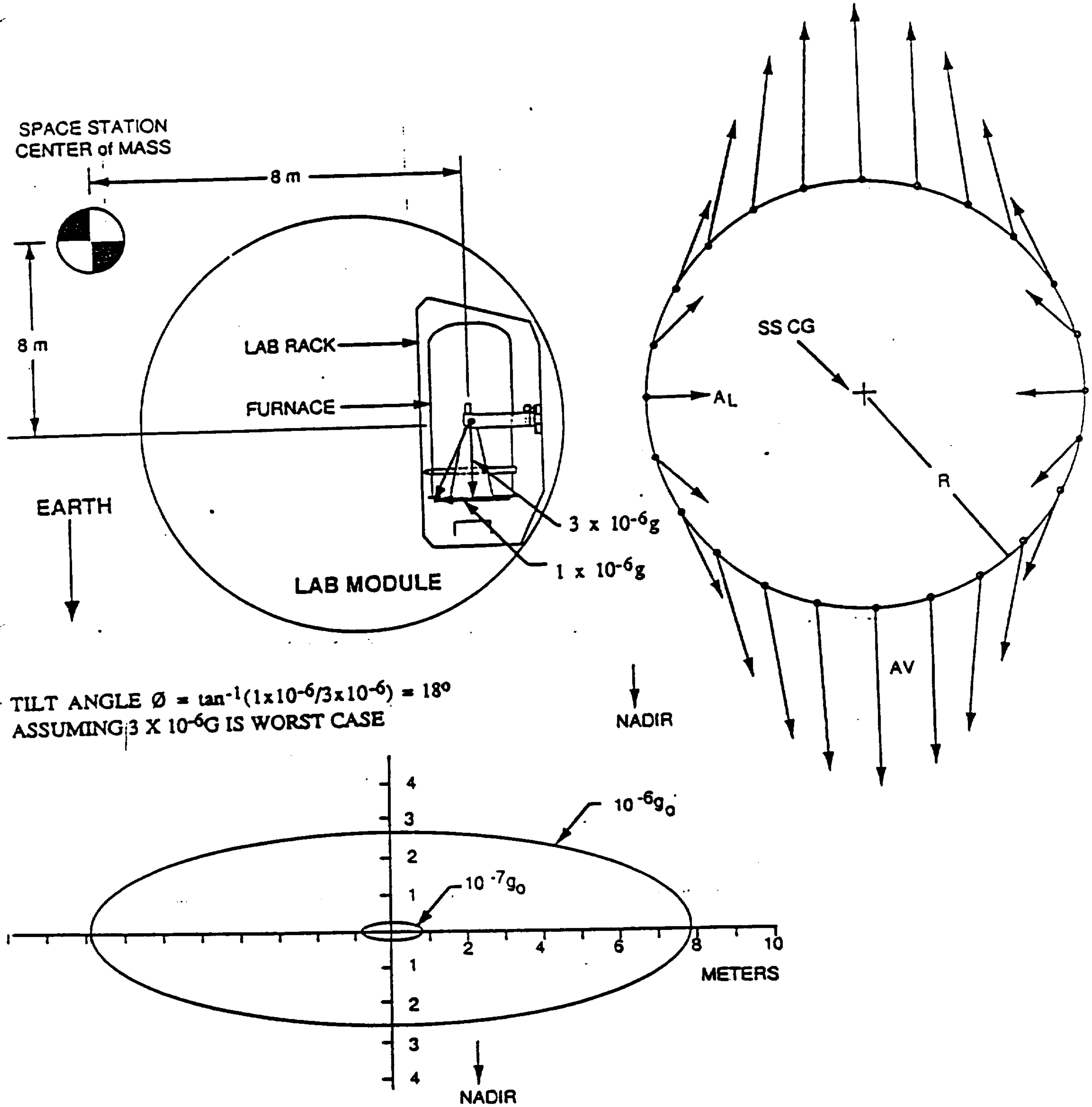
CONCEPTUAL DESIGN

I. ROTATION LIMITS AND DISTURBANCES

The first step required by this study is to determine the disturbances induced on the furnace module by the pointing system. Rotational-induced disturbances are based on maximum normal and tangential acceleration components of 10^{-6} g. Furnace dimensions are based on the Crystal Growth Furnace (CGF) design and assume tracking rotation about the furnace center of mass. A worst-case radius from the center of rotation to the sample of 1.7 ft was used. The maximum allowable angular velocity was calculated to be 4.4×10^{-3} rad/sec or 15 deg/min. The tangential velocity based on ω_{max} was calculated to be 0.007 ft/sec with a minimum acceleration time to ω_{max} of 217 sec. Based on these numbers, the maximum angular acceleration (αmax) is 2.0×10^{-5} rad/sec^2. Based on CGF, the torque induced by rotating the furnace at αmax is 1.7×10^{-2} oz-in. The torque required to rotate the furnace at αmax is unlikely to produce any disturbance on a structure as massive as the space station. Other potential disturbance sources are:

- Stiction in the rotation bearing system
- Drive train noise
- Connection hose binding and interaction.

Calculations of the furnace position during the orbital period are based on a 10^{-3} Hz variation of air drag ranging in magnitude from 3×10^{-6} g to 3×10^{-7} g. Based on the gravity-gradient contour plots and the furnace position shown in Figure 1, the gravity-gradient components were found to be 1.0×10^{-6} g along the truss axis and 3×10^{-6} g in the Earth direction. These components produce a resultant of 3.16×10^{-6} g magnitude at a direction 18 deg off the Earth direction axis. The furnace module will need to be tilted at an 18-deg angle to maintain alignment with this component. The air drag component of 3×10^{-6} g requires a tilt angle of 44 deg from Earth direction for parallel alignment. An air drag component of 3×10^{-7} g requires a tilt angle of 5 deg from Earth direction. Based on these two angles, the furnace must rotate through a 39-deg angle, four times per orbit, or rotate through 39 deg during a 22-min period in a worst-case scenario.



TILT ANGLE $\emptyset = \tan^{-1}(1\times10^{-6}/3\times10^{-6}) = 18^o$
ASSUMING 3 X 10^{-6}G IS WORST CASE

FIGURE 1. CONTOURS OF CONSTANT GRAVITY GRADIENT ACCELERATION IN PLANE PERPENDICULAR TO THE PATH OF THE SPACECRAFT'S CENTER OF GRAVITY (450 km ORBIT)

Assuming the worst case, variation in air drag will be 3×10^{-6} g - (3×10^{-7} g) or 2.7×10^{-6} g; the average angular velocity will be 5.0×10^{-4} rad/sec. This is well below the calculated maximum of 4.4×10^{-3} rad/sec. The rotation about the furnace CG of 5.0×10^{-4} rad/sec will produce a normal acceleration component of 10^{-8}g.

This rotation-induced component must be added to the residual gravity component; however, since this component is almost two orders of magnitude below the resultant residual acceleration component, there would appear to be no significant penalty from rotating the furnace from a disturbance standpoint. See Figure 2.

Based on a limiting tangential acceleration of 10^{-6} g, the minimum time to reach ω_{avg} from a standstill is 13 sec. Angular velocity and acceleration values based on a sinusoidal air drag variation during the orbital period have also been estimated. The maximum angular velocity based on a sinusoidal air drag force variation is 8.21×10^{-4} rad/sec, which produces a maximum normal acceleration component of 3.55×10^{-8} g. The maximum resultant acceleration due to furnace rotation is 1.2×10^{-7} g. A plot of the total rotation-induced acceleration imposed on the furnace is shown in Figure 3.

Assuming a more optimistic estimate of air drag variation from3 $\times 10^{-7}$ to3 $\times 10^{-8}$ g (or a one order of magnitude difference in the maximum values of air drag and gravity gradient), the furnace is required to rotate from 0 to 5.5 deg. The maximum acceleration imposed on the sample by this rotation is 2.8×10^{-10}g.

II. PASSIVE VERSUS ACTIVE ORIENTATION

Because of possible cost and space impacts, a passive alignment system has also been investigated. A passive system will not actively track the residual gravity vector; however, the furnace will still be gimballed to allow orientation with a predetermined "average" g-vector direction that will yield the minimum off-axis disturbance. The passive system would save costs because of the lack of a drive system, drive control electronics, and a dedicated

Based on a worst-case assumption of an air drag component of $3 \times 10^{-6}g$:

$$\phi = \frac{0.66 \text{ radians}}{22 \text{ min.}} = 0.030 \text{ radians / min} = 5.0 \times 10^{-4} \text{ radians / sec.}$$

$$a_n = 1.7 \text{ ft} \times (5.0 \times 10^{-4} \text{ rad/sec})^2 / 32.2 = 1.3 \times 10^{-8}g$$

$$\phi_1 = \tan^{-1}(3 \times 10^{-7}g / 3.2 \times 10^{-6}g) = 5 \text{ deg.}$$

$$\phi_2 = \tan^{-1}(3 \times 10^{-6}g / 3.2 \times 10^{-6}g) = 44 \text{ deg.}$$

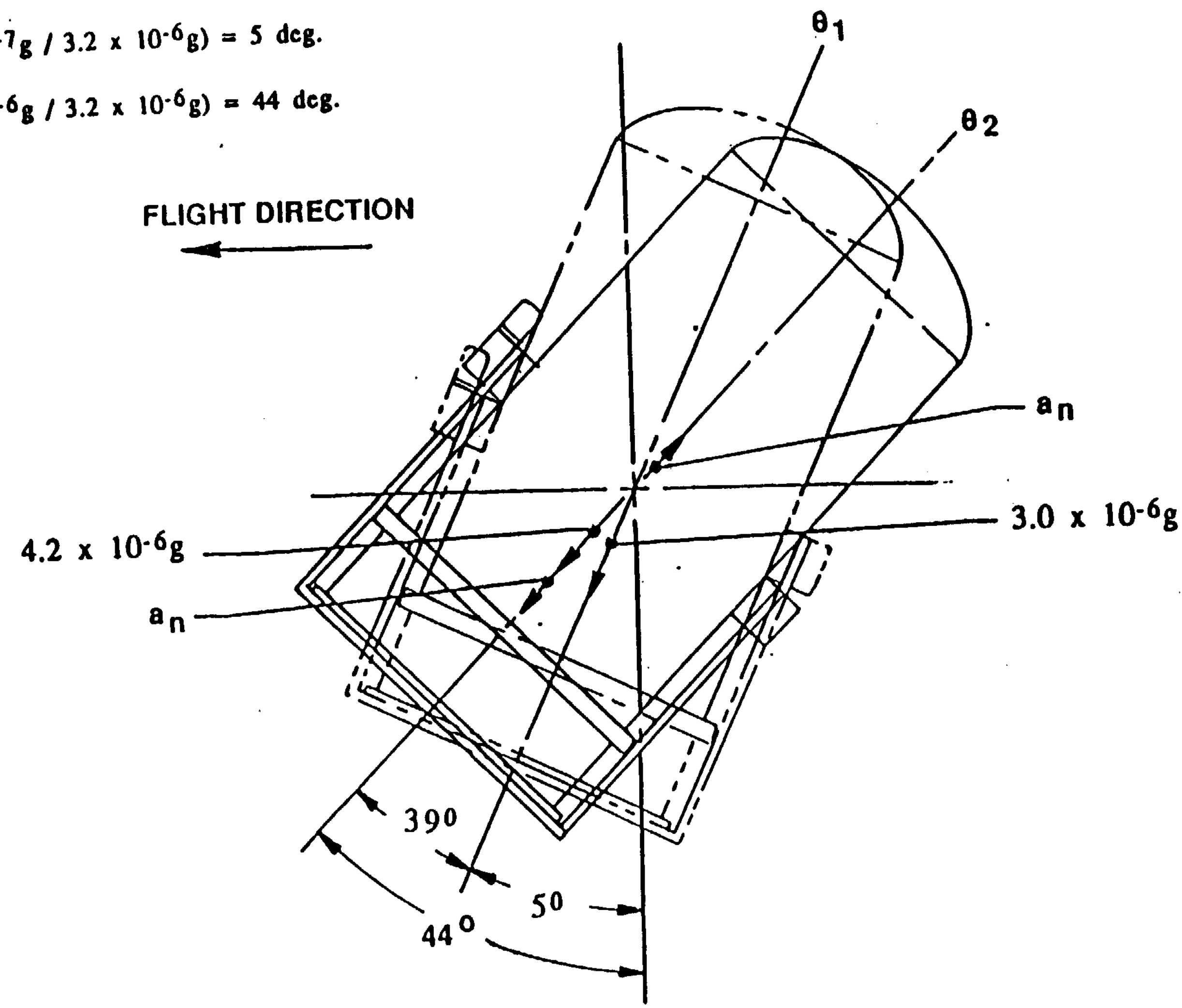


FIGURE 2. WORST-CASE FURNACE ROTATIONS AND ACCELERATIONS

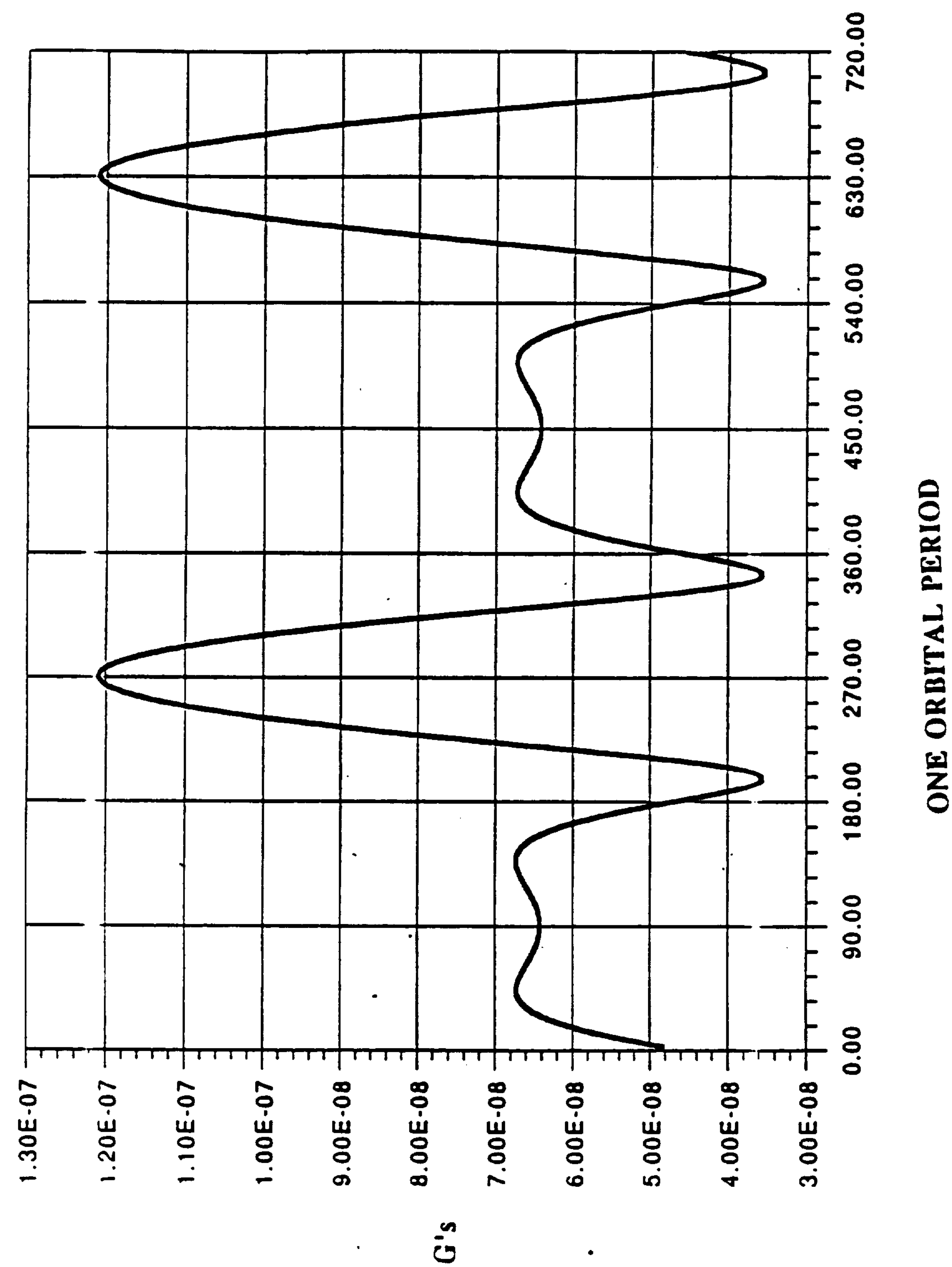


FIGURE 3. ROTATION INDUCED ACCELERATION WORST CASE

accelerometer system. A passive system could be designed to align with the gravity-gradient component only (rotation on one axis only) or align with the resultant of the gravity gradient and the average air drag component (rotation on two axes).

Alignment with the gravity-gradient component only will produce a cyclic orientation error equal to the air drag component. Alignment with the average (worst case) air drag vector orientation at 25 deg from the Earth direction axis will produce a maximum off-axis acceleration component of 1.4×10^{-6} g. See Figure 4. Fixed alignment with the average air drag force position (2.5 deg), if the maximum air drag force is 3×10^{-7} g, yields an off-axis acceleration component of 5×10^{-7} g.

The passive-active system trade will be determined by the maximum air drag force, the orientation system tracking accuracy, and the maximum off-axis acceleration component allowed by the science requirements. Three cases are examined.

Case 1

a) Air drag varies from 3×10^{-6} to 3×10^{-7} g.

b) Tracking accuracy is 1.0 deg.

c) Gravity gradient is 3×10^{-6} g.

d) Two double rack spaces are available.

These conditions yield a maximum off-axis acceleration component of 1.4×10^{-6} g if the furnace is in a stationary position 24 deg from the Earth direction axis (this is the rotation midpoint position). The resultant position of the two dominant acceleration components varies from ~5 to 44 deg. A tracking accuracy of ±1.0 deg, if an active system is incorporated, will produce a maximum off-axis error component of 7.3×10^{-8}g.

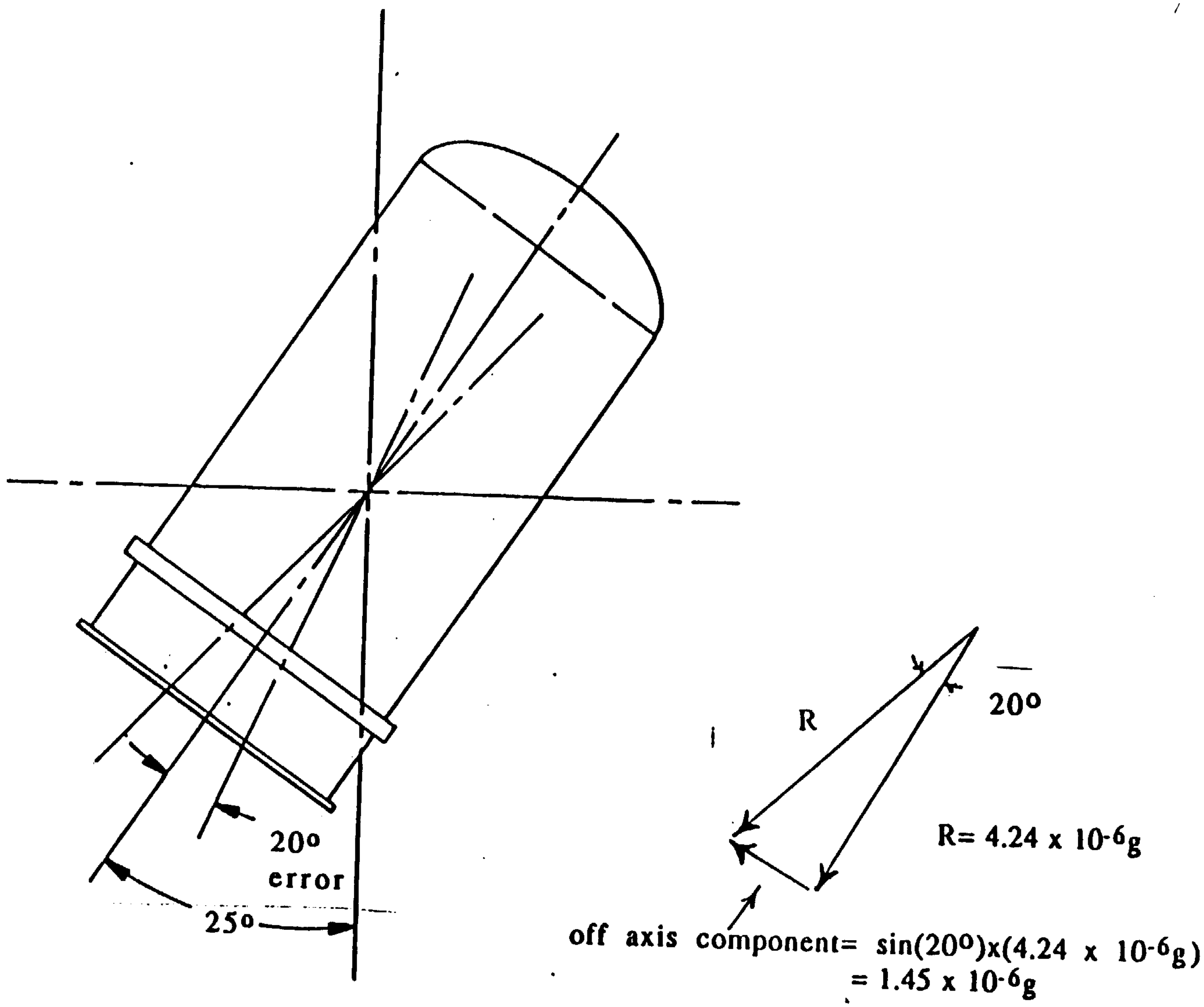


FIGURE 4. ERROR PRODUCED BY A PASSIVE SYSTEM

<u>Case 2</u>

a) Air drag varies from 3×10^{-6} to 3×10^{-7} g.

b) Gravity gradient is 3×10^{-6} g.

c) Tracking accuracy is 1.0 deg.

d) Only one double rack space is available

These conditions produce a maximum off-sample axis acceleration component of 1.9×10^{-6} g if the furnace is in a stationary position 17 deg from the Earth direction axis (this is the maximum rotation angle in the double rack). The 1.0-deg tracking accuracy will produce a maximum off-axis acceleration component of 1.75×10^{-7} g.

<u>Case 3</u>

a) Air drag varies from 10^{-6} to 10^{-7} g.

b) Tracking accuracy is 1 deg.

c) Gravity gradient is 3×10^{-6}g.

The resultant position of the two dominant acceleration components varies from 2 to 18 deg. This variation falls within the space envelope provided by the standard double rack, therefore active tracking is possible within the standard double rack space but may not be required due to the maximum off axis acceleration limit of 1.0×10^{-6}g.

The current requirements document specifies a maximum off-axis accceleration component of 1×10^{-6}g below 0.020 hz. Based on this requirement a passive system is recommended if the maximum air drag is below this level. An active tracking system is required if the maximum air drag is above the 1×10^{-6}g level.

III. FURNACE ORIENTATION SYSTEM

Several concepts for orientation systems have been explored. The basic design parameters for an active system are as follows:

- ±20-deg movement required on a radial plane through the lab module
- 45-deg movement for air drag compensation - this will probably require a special rack space at least 64 in. wide
- Minimum or no entry into the lab aisle space
- The system must accommodate various sized and shaped furnace modules
- Hose and electrical connection provision
  - Fluid connection
  - Inert gas
  - Heater power
  - Vacuum
  - Instrumentation.

The space requirements for rotation about two axes are shown in Figure 5. The space required will depend on the furnace diameter, length and the required angles of rotation. The rotation angles shown in the figure are based on a 24-in. diameter furnace module, 54 in. long. It becomes immediately obvious that furnace module containers as large as CGF will not be compatible with the system. Furnace modules will probably be required to be at least 25 percent smaller in length. This will probably produce a corresponding reduction in sample length.

The impact of a sample size reduction on the science requirements will need to be determined. If 45-deg rotation on the air drag connection axis is required, it will be necessary to use two double rack spaces or at least 64 in. of wall space depending on the furnace size.

Concept I, shown in Figure 6, consists of a tilt stage at the base of the rack for gravity-gradient correction and the second rotation point for air drag correction located at the furnace CG position. An L-shaped structure connects the tilt stage and the rotation gimbal. This configuration has a space disadvantage.

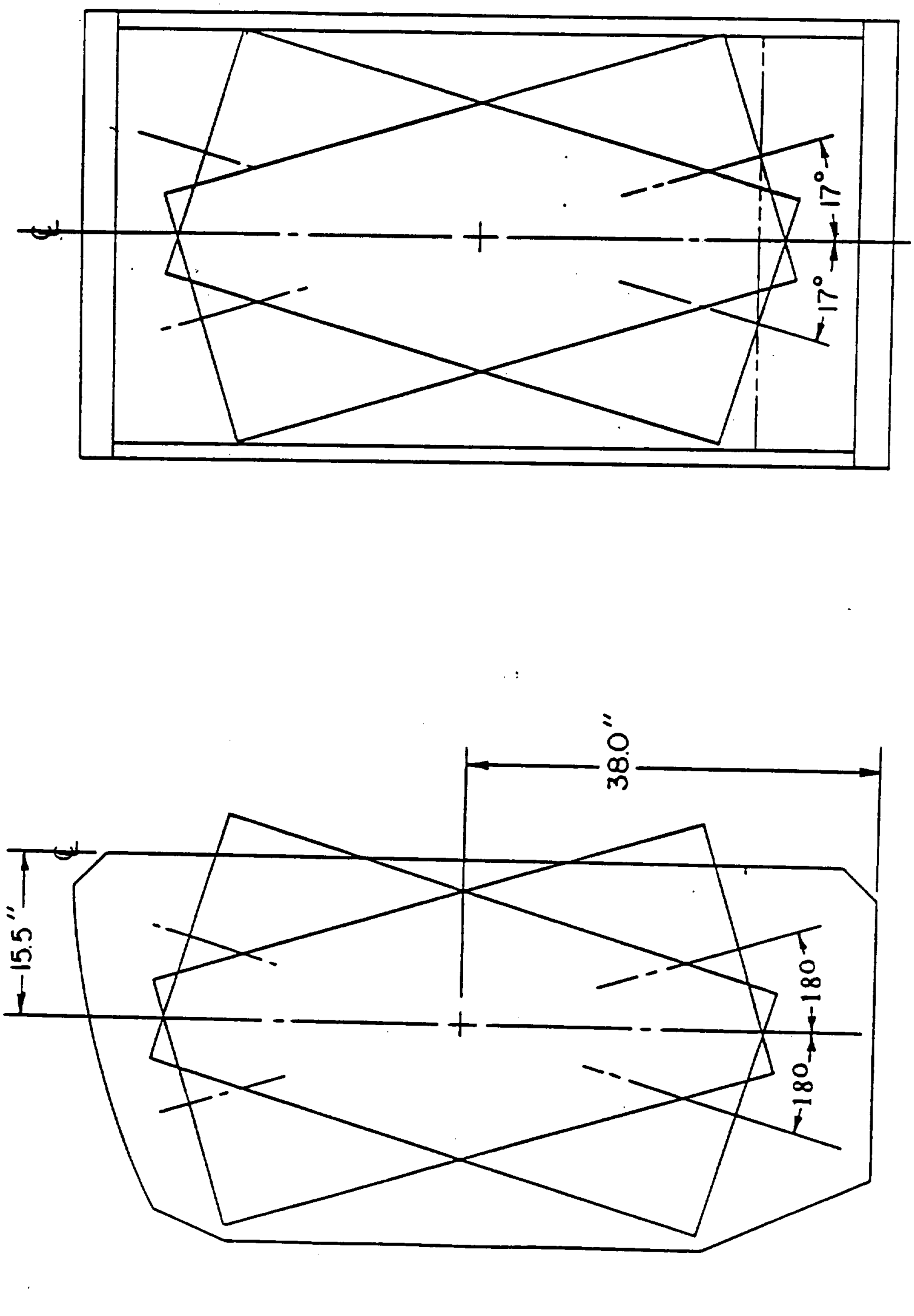


FIGURE 5. MAXIMUM TILT ANGLES - DOUBLE RACK

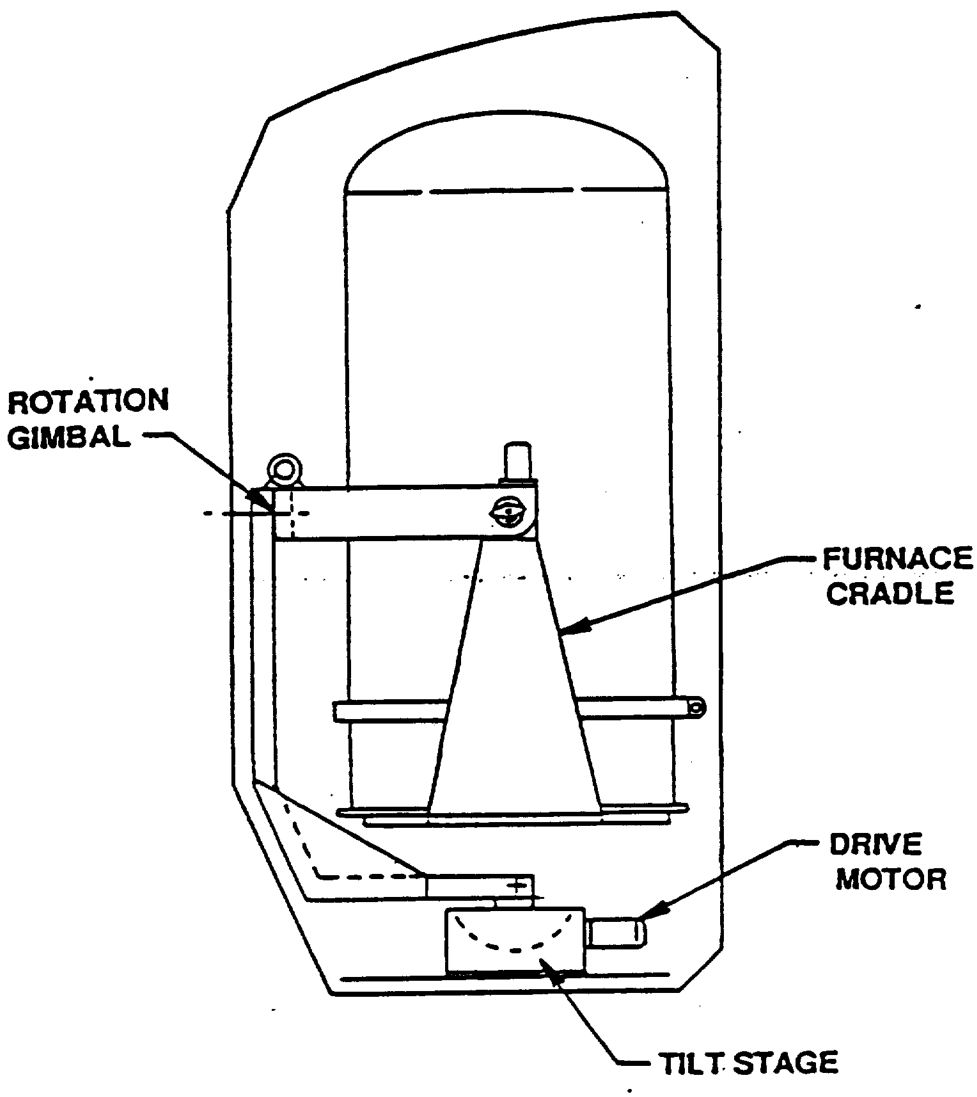


FIGURE 6. CONCEPT 1

The base stage and the arm from the base to the upper rotation gimbal intrude on the furnace space and limit the rotation angles, furnace length, and furnace diameter.

Concept II places both of the rotation gimbals in the same plane. See Figure 7. The gimbal structure is still supported from the base of the rack. This configuration is more space efficient than concept I and allows both rotation points to be located in the same plane.

Concept III places both rotation points in the same plane, as in concept II, but uses a special rack which allows mounting of the longitudinal (air drag) rotation point on the back wall of the rack. See Figure 8. This configuration allows a larger tilt angle and/or furnace module size by elimination of the rack base support arm. However, this configuration will require the design and construction of a special lab rack.

If the standard double rack space is used, the furnace length is limited to 34 in. with a 17-in. diameter (EAC) container (assuming 45-deg air drag rotation). See Figure 9. Further reductions in furnace diameter will only yield a length increase of 4 in. Based on the standard rack depth and a 18-deg gravity-gradient alignment angle, a 24-in. diameter (CGF size) furnace container is limited to a length of 54 in. With this size furnace container, 59 in. of wall space is required to accommodate a 45-deg rotation. See Figure 10. The EAC container diameter of 17 in. will allow a furnace container length of approximately 64 in. with the standard rack depth and an 18-deg gravity-gradient tilt angle.

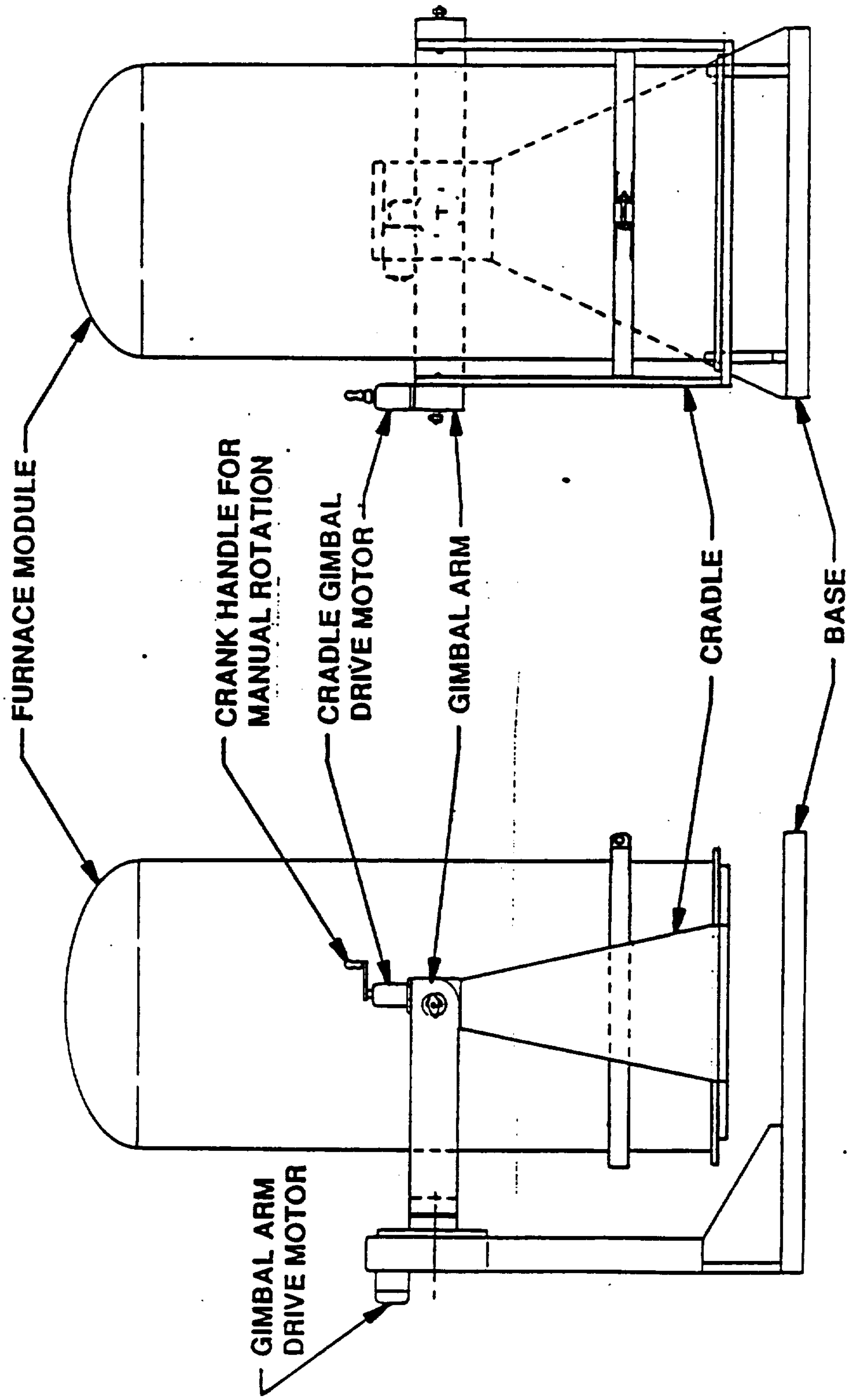


FIGURE 7. CONCEPT 2

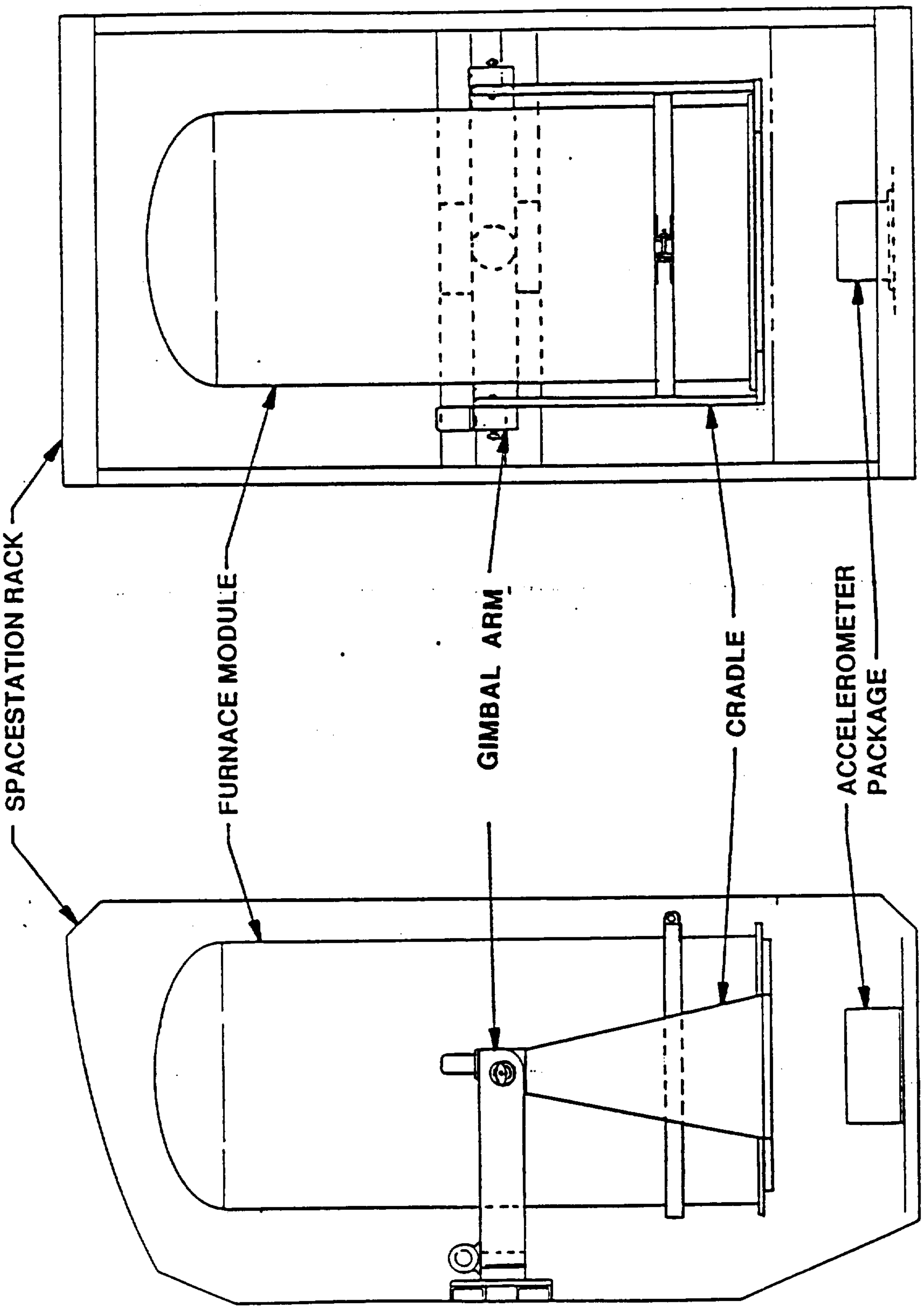


FIGURE 8. CONCEPT 3

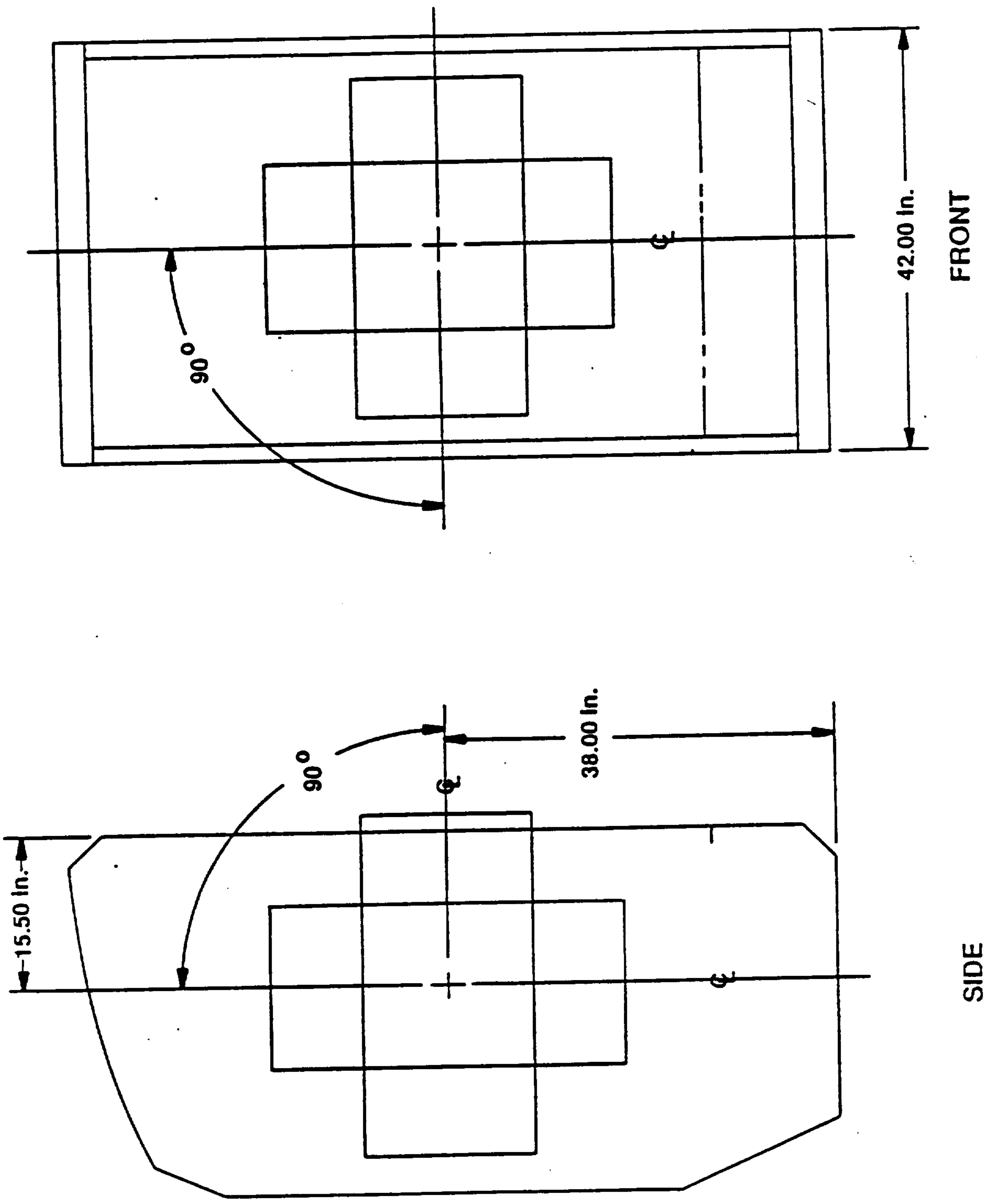


FIGURE 9

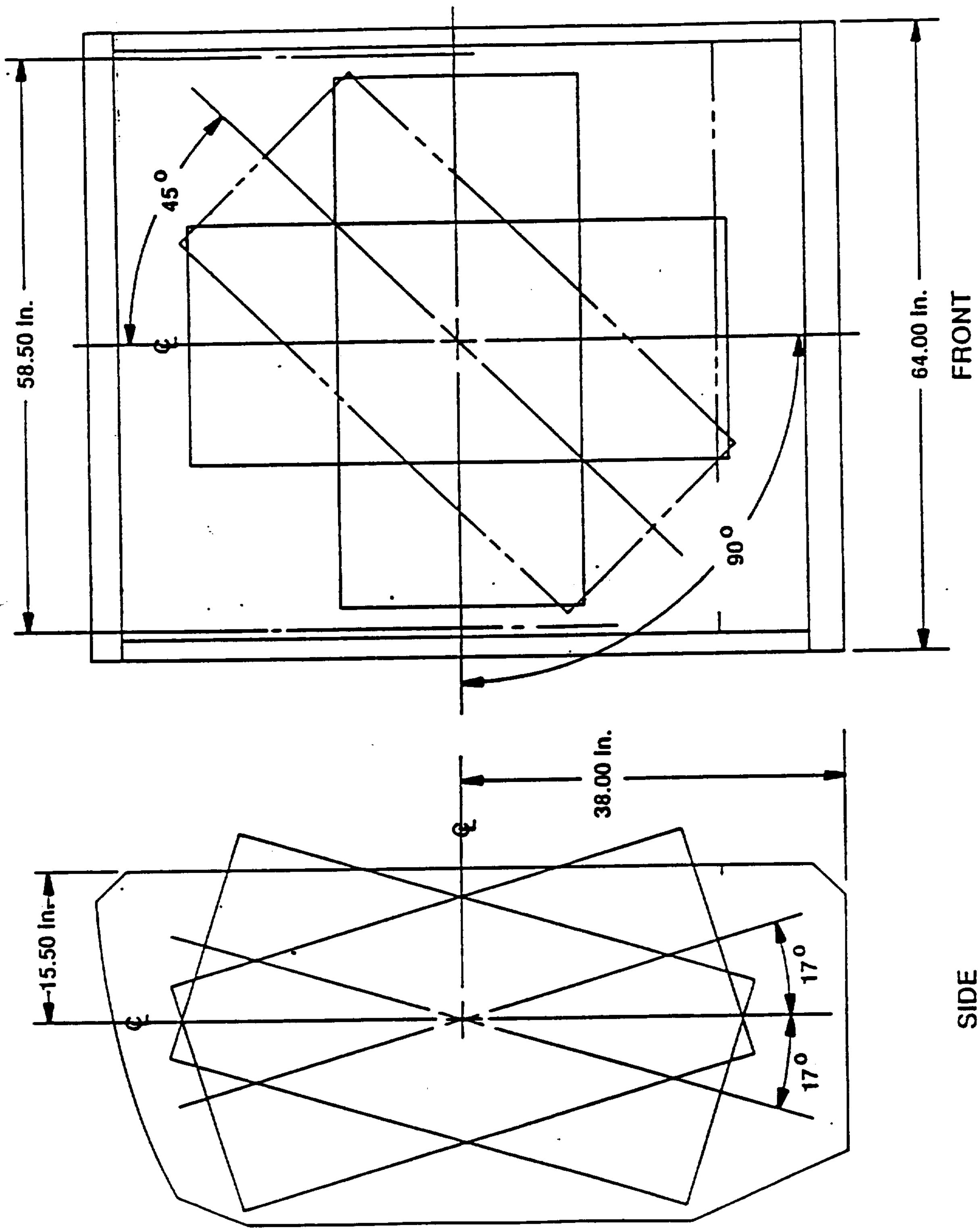


FIGURE 10. FURNACE SPACE REQUIREMENT

The impact of the reductions in sample diameters and lengths on the science requirements of potential experiments needs to be examined. The orientation system will also have impacts on the design of an automated sample exchange system and may possibly rule out the inclusion of such a system.

A special wide rack poses the additional problem of entry into the lab module through the 50-in. wide hatch. The problem requires further examination. One possible concept, shown in Figure 11, would utilize a folding structure that would fit within the space of two racks. The furnace gimbal assembly would be mounted on a "backbone" structure. This structure would have foldout arms, which would connect with the lower rear attach points in the lab module. This same concept is shown tilted forward in the removal configuration in Figure 12.

The 45-deg rotation requirement in the air drag correction plane may be reduced to less than 17 deg if reliable air drag calculations show that the air drag component will always remain at least one order of magnitude below the gravity-gradient component. A 17-deg maximum rotation angle will allow the orientation system to fit within the standard double rack space. Furnace module length will still be restricted to 54 in. with a 24-in. diameter.

Since the furnace enclosure cans are likely to be thin walled, a furnace support or cradle will need to be provided to support the furnace module at the base. The cradle must be designed to provide on-orbit furnace module interchangeability. The concept for furnace module changeout is shown in Figure 13. There are two changeout concepts. One concept uses a furnace module dedicated support cradle. The entire cradle assembly would be changed with the furnace module. The cradle will be designed so that the distance between the rotation hubs accommodates the largest diameter furnace module envisioned.

The cradle would be located by two splined and removable axles. Module changeout would involve removing a locking pin, retracting both axles through the gimbal spindles, and removing the cradle.

All hose and electrical connections would be broken at the support cradle.

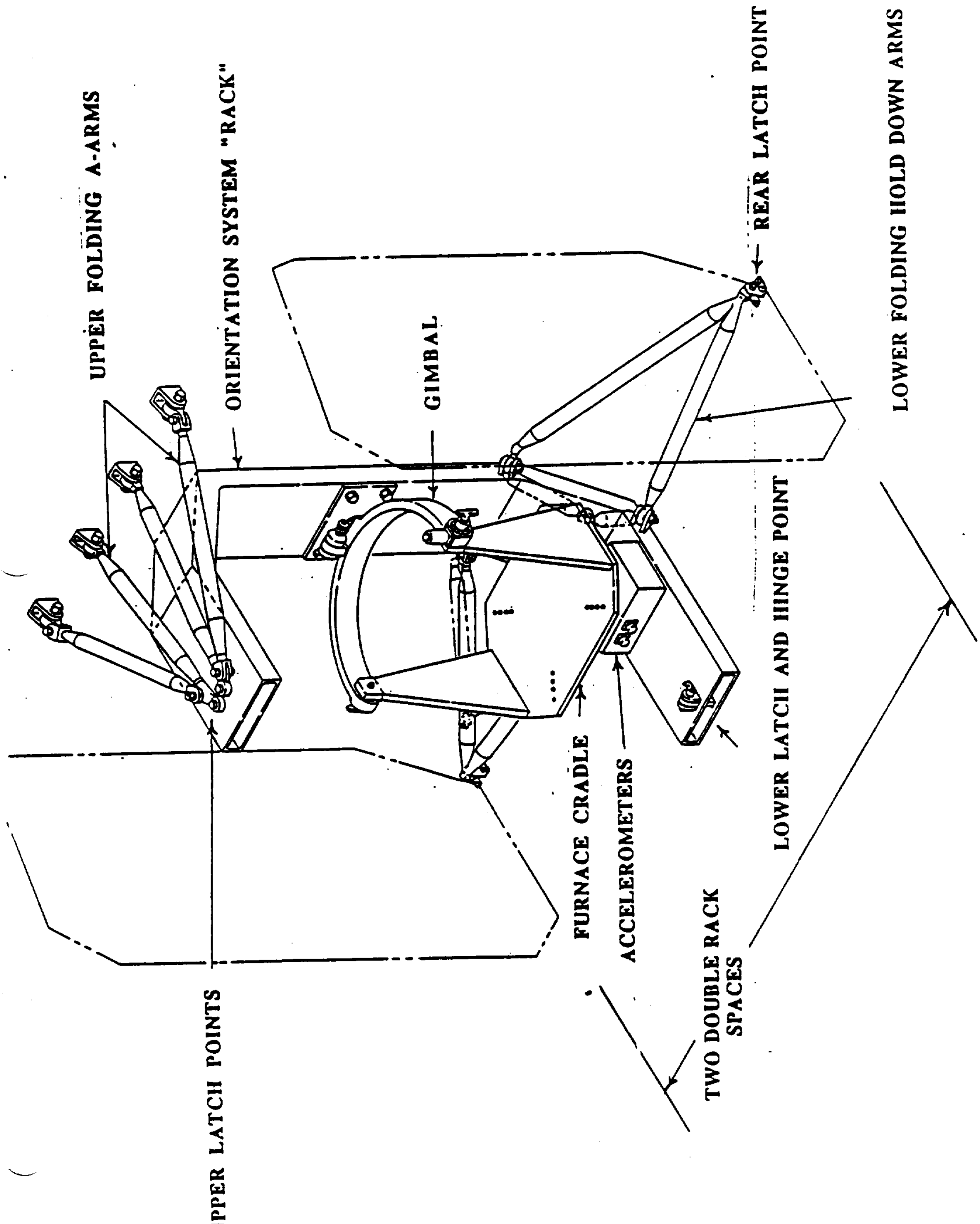


FIGURE 11. FURNACE ORIENTATION SYSTEM

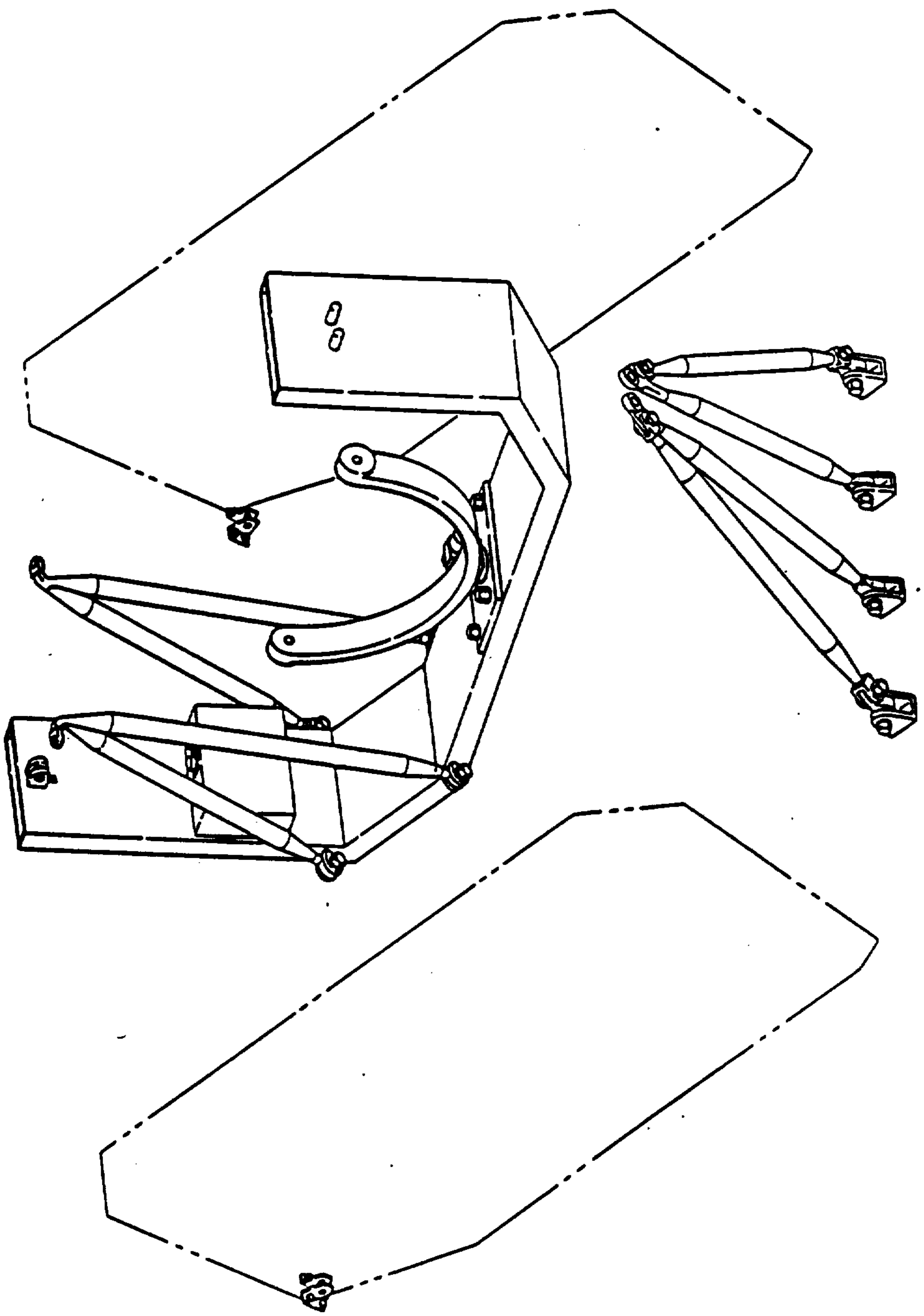


FIGURE 12. RACK REMOVAL CONFIGURATION

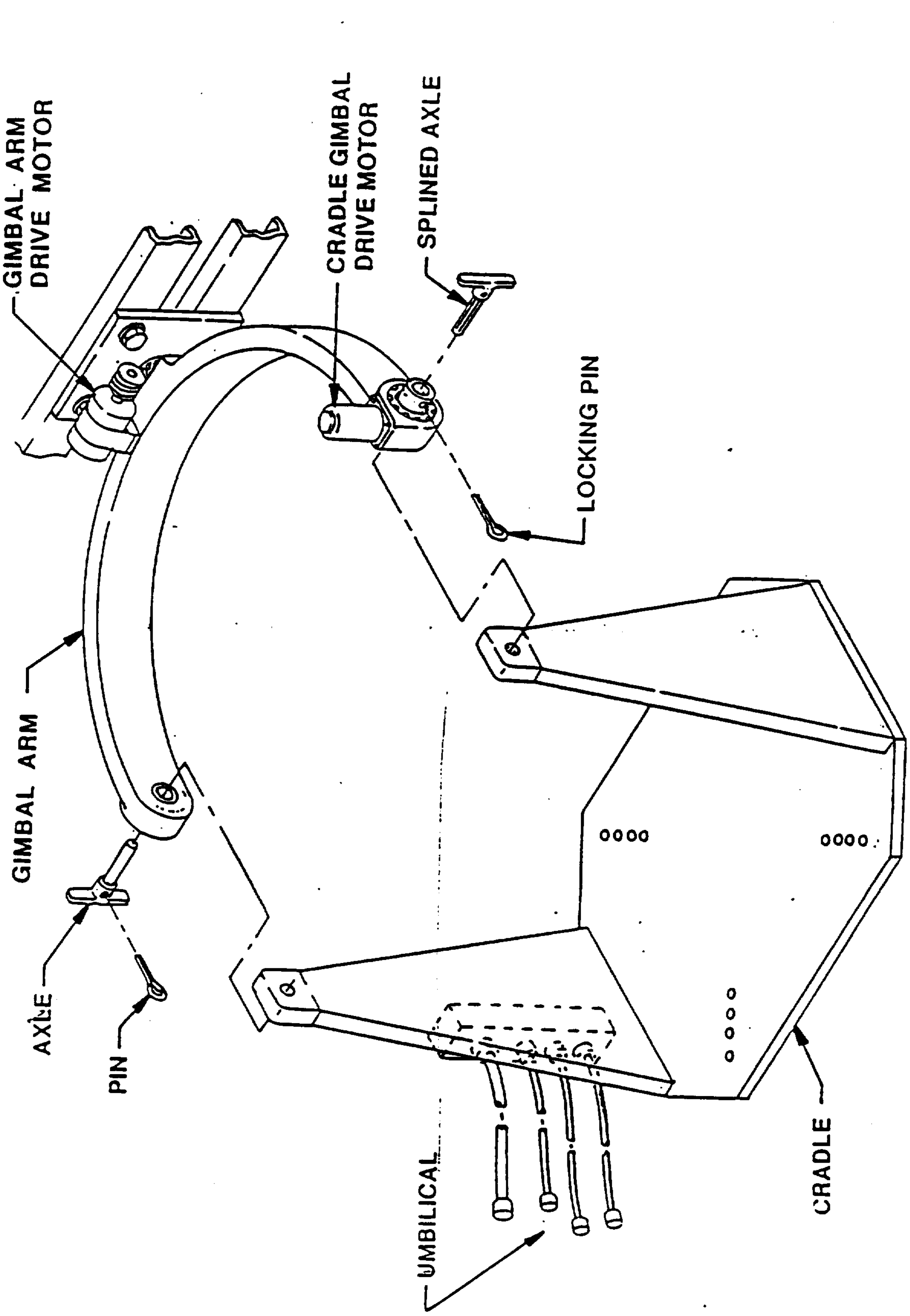


FIGURE 13. ORIENTATION GIMBAL CONCEPT

In the second concept, the support cradle is integral with the rotation gimbal. The front of the cradle is open to allow removal and insertion of the furnace module. Each furnace module would require a base adapter plate for connection with the cradle baseplate. Hose and electrical lead breaks would be made at the base of the furnace module. This system offers potentially easier module changeout, but may introduce design restraints on the various furnace modules.

IV. SUBSYSTEM REQUIREMENTS

- Accelerometer Subsystem
  - 10^{-7} g sensitivity at 10^{-3} Hz or one order of magnitude less than the minimum acceleration to be measured
- Accelerometer Signal Conditioners
  - Filtering and Amplification
- Accelerometer Data Management System
  - Processing of signal conditioner output
  - Determination of residual g-vector orientation
  - Storage of pertinent acceleration data
- Drive Motor Power Supply and Control System
- Drive Motor System and Position Sensors - positioning accuracy to 1.0 deg
- Flexible connection system
- Accelerometer calibration system
- Accelerometer vibration isolation system.

V. SAFETY ISSUES AND HAZARDS

- Flexible connection failure
  - Fluid and gas connection
  - Power connection
  - Vacuum connection
  - Instrumentation

- Failure of the rotation system drive mechanism may allow unrestrained rotation of the furnace module
- Crew entry into the furnace motion space. It will probably be necessary to provide torque limiting slip clutches in the rotation mechanism
- Crew injury during furnace module changeout.
- Touch Temperature limitations on furnace components protruding out of the rack envelope.

TECHNOLOGY DEVELOPMENT ISSUES

I. ACCELEROMETER SYSTEM

A three-axis accelerometer system is required for the purpose of determining the residual g-vector direction and magnitude. The accelerometer system must be capable of measuring accelerations of 10^{-7} g at frequencies of 10^{-3} Hz. This requirement may be increased to 10^{-8} g as the space station configuration and air drag estimates are refined. The accelerometer should have a resolution one order of magnitude greater than the minimum acceleration. Preliminary investigations (TBE Workpackage I) indicate the Sundstrand QA-2000, Bell Model II, and the Bell MESA are the only currently available accelerometers capable of coming close to meeting these requirements. The QA-2000 and the Model II are marginal at best (10^{-6} g). Tests indicate the Bell MESA accelerometer may have problems with limited dynamic range and will require extensive vibration isolation. The Sundstrand Advanced Strap Down Accelerometer (ASDA) looks promising, but it is still in the development phase. Accelerometer testing at TBE has been terminated because of a stop-work order on Workpackage I. It is unsure how verification of accelerometer performance will be obtained in the future.

II. ACCELEROMETER CALIBRATION SYSTEM

Accelerometers such as the Sundstrand QA-2000 have exhibited bias drifts as high as 3×10^{-7} g/h. Therefore, a periodic calibration technique must be developed to ensure bias correction.

III. ACCELEROMETER VIBRATION ISOLATION SYSTEM

Either an active or passive vibration isolation system will be needed to prevent accelerometer saturation at high noise levels.

CONCLUSIONS

This study has determined that a furnace orientation system is feasible. The recommended configuration is that which would allow active tracking of the residual gravity component. This recommendation is based on the assumptions that the maximum air drag acceleration is of the same order of magnitude as the gravity gradient acceleration and science requirements dictate an off-axis acceleration component no greater than 10^{-6} g. If the maximum air drag component falls below 10^{-6}g and the system is limited in space to one double rack, then a passive orientation system is recommended. This concept for an active tracking system is illustrated in Figure 14. The following design features are incorporated in the active tracking system:

- Rotation gimbals in a common plane.
- Furnace modules are base mounted.
- The air drag correction gimbal is wall mounted.
- The system will accept a 24-in. diameter, 54-in. long experiment container (provided rack space requirements are met).
- Furnace module umbilical connection breaks are made at the support cradle.
- Gimbal rotation points are driven by stepper motors in microstepping mode
- Rotation points are driven through worm and anti-backlash worm gears incorporating a self-locking gear ratio and torque limiting slip clutches. Gear train related noise will need to be investigated.[1]
- The gimbal support system folds to allow for hatch clearance (requires further study).
- 45-deg rotation on the air drag correction axis; 20-deg rotation on the gravity gradient correction axis (assuming the worst possible case situation where air drag and gravity gradient are of the same magnitude)[2]

1 There do not appear to be any problems with bearing related noise or stiction at the low angular velocities. It is recommended

TBS

FIGURE 14. ACTIVE TRACKING SYSTEM CONCEPT

that a wet lubricant be used, that the bearings be preloaded, and the bearings be sized to allow at least one complete ball rotation.

2 The air drag correction axis rotation requirement may be reduced to 17 deg. This will allow the system to fit within a standard double rack space. The air drag acceleration force must be one order of magnitude less than the gravity-gradient acceleration force.

The conclusions are based on the following assumptions:

- The U.S. lab module is located at the position shown in Figure 1.
- 3×10^{-6}g gravity gradient component.
- Air drag axis parallel with lab module longitudinal axis.
- The space station exhibits no roll during orbit.
- The system size is within the space station rack space requirements.
- Sample sizes dictated by the orientation system do not violate science requirements.
- Accelerometers of the required resolution and stability become available.
- 10^{-3} Hz air drag force variation.

It is recommended that each drive motor be provided with a hand crank for manual operation of each rotation point in the event of a drive system failure. The accelerometer package should be located as close as possible to the furnace module, preferably directly under or over the orientation cradle.

The passive system configuration will be similar to the active system, but will not require drive motors for the rotation points. Furnace orientation may be achieved through manual rotation of the gimbal. If the maximum air drag component is less than 10^{-6} g, then orientation capability is required only on the gravity-gradient alignment axis.

PHYSICAL ACCOMMODATION REQUIREMENTS FOR AN ACTIVE POSITIONING SYSTEM

Component	Mass (kg)
Furnace Cradle Assembly	10
Gimbal Arm	15
Drive Motors (2)	3
Accelerometer Package	10
Gimbal Support Structure/Rack	TBD

Space Requirements:

Worst-Case Assumption Based Configuration - 2 Double Racks
Optional Configuration - 1 Double Rack

Power Requirements:

Drive Motors (2) - 50 W
Accelerometers (6 at 0.3 W/ea.) - 2 W
Control Electronics - TBD

RECOMMENDATIONS FOR FURTHER STUDY

- Orientation system space requirements
- Crew assembly and interaction requirements
- Sample exchange problems
- Cost impacts of a furnace module logistics carrier
- Assembly procedures

APPENDIX E

SPACE STATION FURNACE FACILITY ACRONYMS AND ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

AADSF	Advanced Automated Directional Solidification Furnace
ac	Alternating Current
AR	Atmospheric Revitalization
ARS	Atmospheric Revitalization System
BCD	Baseline Configuration Document
BER	Bit Error Rate
BIT	Built-In Test
BITE	Built-In Test Equipment
bps	Bits per Second
C	Centigrade
C&T	Communications and Tracking
C&W	Caution and Warning
CdTe	Cadmium Teluride
CCTV	Closed Circuit Television
CCZ	Command and Control Zone
CDR	Critical Design Review
CG	Center of Gravity
CGF	Crystal Growth Furnace
CHeCS	Crew Health Care System
cm	Centimeter
cm^3	Cubic Centimeter
CMDS	Commands
Coax	Coaxial (cable)
COMMS	Communications System
CO_2	Carbon Dioxide
COP	Co-orbiting Platform
cu. m.	Cubic Meter
dB	Decibel
db(A)	Decibels Absolute
DBMS	Data Base Management System
dc	Direct Current
DDT&E	Design, Development, Test, and Evaluation

ACRONYMS AND ABBREVIATIONS (Cont.)

deg	Degree
DMS	Data Management System
EAC	Experiment Assembly Container
ECLSS	Environmental Control and Life Support System
ECR	Engineering Change Request
EDCO	Extended Duration Crew Operations
EEE	Electrical, Electronic, and Electromechanical
e.g.	For Example
EGSE	Electrical Ground Support Equipment
EHS	Environmental Health Subsystem
EM	Electromagnetic Energy
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPS	Electrical Power System
ESA	European Space Agency
F	Fahrenheit
FBCC	Full Body Cleansing Compartment
FDIR	Fault Detection, Isolation, and Recovery
FDS	Fire Detection and Suppression
FMS	Fluid Management System
fps	Feet per Second
FS	Factor of Safety
FSE	Flight Support Equipment
ft	Foot, Feet
FTS	Flight Telerobotic Servicer
g	Force of Gravity
GaAs	Galium Arsinide
GFE	Government-Furnished Equipment
GFI	Ground Fault Interrupt
gm	Gram
GMT	Greenwich Mean Time
GO_2	Gaseous Oxygen

ACRONYMS AND ABBREVIATIONS (Cont.)

GOX	Gaseous Oxygen
GPS	Global Positioning System
GSE	Ground Support Equipment
Hg	Mercury
HgCdTe	Mercury Cadmium Teluride
HgZnTe	Mercury Zinc Teluride
HMF	Health Maintenance Facility
HSO	Habitation/Station Operations
HWFZ	Hot Wall Float Zone Furnace
Hz	Hertz (Cycles per Second)
IAS	Internal Audio System
IA&V	Internal Audio and Video
IFEA	Integrated Furnace Experiment Assembly
IMS	Inventory Management System
in.	Inch
INS	Integrated Nitrogen System
IOC	Initial Operational Capability
IR	Infrared
IRD	Interface Requirements Document
ISF	International Space Facility
ISO	International Standard Organization
IVA	Intravehicular Activity
IVS	Internal Video System
IWFS	Integrated Waste Fluid System
IWS	Integrated Water System
JSC	(Lyndon B.) Johnson Space Center
kbps	Kilobits per Second
KCAL	Kilocalories
kg	Kilogram
kHz	Kilohertz (Kilocycles per Second)
km	Kilometer
KSC	Kennedy Space Center

ABBREVIATIONS AND ACRONYMS (Cont.)

kW	Kilowatt
La	Level Absolute
LAB	Laboratory
Leq	Level Equivalent
lb	Pound
LOS	Line of Sight Loss of Signal
LOX	Liquid Oxygen
LSA	Logistics Support Analysis
LUX	One Lumen per Square Meter
LVLH	Local Vertical/Local Horizontal
MASA	Metals and Alloys Solidification Apparatus
mg	Miligram
m	Meter
m^2	Square Meter
m^3	Cubic Meter
Max	Maximum
mbps	Megabits per Second
MDMS	Maintenance Data Management System
MEQ	Man-equivalent
mg	Milligram
MGSE	Mechanical Ground Support Equipment
min	Minimum Minute
MIP	Million Instructions per Second
mm	Millimeter
MMO	MSC Maintenance Depot
MMU	Manned Maneuvering Unit
MOU	Memorandum of Understanding
Mr	Milliradian
MS	Margin of Safety
MSFC	(George C.) Marshall Space Flight Center

ABBREVIATIONS AND ACRONYMS (Cont.)

MSIS	Man-Systems Integration Standards
MSS	Mobile Servicing System
MT	Mobile Transporter
N	Newton
N_2	Nitrogen
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NC	Noise Criteria
NCRP	National Council on Radiation Protection and Measurement
NDE	Nondestructive Evaluation
NHB	NASA Handbook
NIM	Network Interface Manager
nm	Nanometer
NOS	Network Operating System
N.R.	Not Required
NSTS	National Space Transportation System
O_2	Oxygen
O/A	Operations/Administrative
OASPL	Overall Absolute Sound Pressure Level
OMA	Operations Management Application
OMS	Operations Management System
OPS	Operations
ORU	Orbit Replaceable Unit
OS	Operating System
OSE	Orbital Support Equipment
OSI	Open System Interconnection
OTV	Orbital Transfer Vehicle
OWS	Operations Workstations
PDCA	Power Distribution and Control Assembly
PDR	Preliminary Design Review
PDRD	Program Definition and Requirements Document
PHC	Personal Hygiene Compartment

ABBREVIATIONS AND ACRONYMS (Cont.)

PHS	Personal Hygiene System
PMA	Platform Management Application
PMAD	Power Management and Distribution
PMC	Permanently Manned Capability
PMMS	Process Materials Management Subsystem
PMS	Platform Management System
Press	Pressure
Prox Ops	Proximity Operations
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
QA	Quality Assurance
r	Radian
REM	Roentgen-Equivalent-Man
RF	Radio Frequency
RFI	Radio Frequency Interference
SAP	Service Access Points
SCTS	Space Cargo Transportation System
SD	Solar Dynamic
sec	Second
SI	International System of Units
SM	Systems Management
SMAC	Spacecraft Maximum Allowable Concentrations
SMM	System and Mission Management
SOW	Statement of Work
SPDM	Special Performance Dexterous Manipulator
SPL	Sound Pressure Level
SPM	Solar Power Modules
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRD	System Requirements Documents
SS	Space Station
SSCB	Space Station Control Board
SSCBD	Space Station Control Board Directive

SSFF Safety Hazard Reports

Development of SSF Payload facilities present problems that are unique because of design requirements for long term operations, contamination, and on-orbit maintenance. Additional payload problems can be ascribed to: the immaturity of the space program requirements; immature definition of space station services; and organizational interfaces that deter maximum utilization of NASA's previous space experience.

In December 1990, there was a joint meeting of MSAD, the STS Payload Safety Panel, Dr. Bonnie Dunbar, the designated chairman of SSF Payload Safety Panel (L. Perez), and several NASA centers at Johnson Space Center. This meeting discussed several common problems including Safety Requirements. Although there were several good suggestions for facility designs and safety requirements, the principal result was that safety requirements would be based on NSTS 1700.7B. Based on the SSFF program, the following concerns and recommendations are provided.

1. Safety Requirements

Safety Requirements are not fully established. There have been several review issues of requirements issued as: NSTS 1700.7B Addendum 1, NHB 1700.7C, and SSP 30XXX. While much of the proposed requirements are similar, the differences make "final designs" risky to the development agency.

Recommendation: Establish a unified approach, identify the final safety Arbiter, and baseline safety requirements.

2. Toxicity

Material processing facilities frequently produce (offgassing or vapors) products that would be toxic if released into habitable areas. Depending on the degree and quality of toxic materials, safety requirements mandate a pressure vessel or two or three levels of containment. On Spacelab missions, the operation of furnaces at a vacuum or negative pressure (in relation to the module) have been deemed the equivalent of one level of containment. Because potential contamination problems surround the Space Station, requirements have been established to ensure that contaminants including toxic gases are not released into the vacuum vent. This requirement will necessitate an additional containment level for processing, or a containment system for released products.

Recommendation: Consider the use of filters to enable release of toxic materials into the vacuum vent line. As currently written, it is doubtful that module air could be vented.

3. Experience Factors

NASA has a wealth of knowledge concerning processing facility design that has been acquired in the manned Spacelab program. This experience, though scattered at various centers, it principally located at MSFC and JSC. Because the experienced personnel are mostly involved in Spacelab, there is very limited contact with Space Station. This experience includes both design and safety.

Recommendation: Develop panels/work groups composed of SL experienced personnel to meet occasionally with Space Station developers to answer questioning or relate Spacelab resolution to problems.

Safety Panel:

Implementation of the SS Flight Payload Safety Panel is scheduled for mid to late 1992. There are numerous questions by payload developers that need guidance in design or interpretation of safety requirements. Early guidance in the interpretation of safety requirements could save considerable redesign at a later date with attendant costs.

Recommendation: Implement the PSP at the earliest possible date to enable clarification or interpretations of safety requirements.

The SSFF study effort generated the following Hazard Reports based on the requirements and protocols defined in Appendix B of NHB 1700.7B (Space Station Requirements).

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Electrical Shock	G-1
SUBSYSTEM: Electrical	**HAZARDOUS CONDITION DESCRIPTION:** Electrical shock to crew from contact with voltage sources.	**REVIEW:** Phase 0 **DATE REVISION:**
AFFECTED INCREMENT(S): TBD	**OPERATIONS:** Experiment Electrical Operations	**HAZARD STATUS:** ☑ OPEN ☐ CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
☐ GROUND OPERATIONS ☐ LAUNCH/RETURN ☐ ON-ORBIT TRANSFER ☑ ON-ORBIT OPERATIONS	Crew	SSP 30652 (NSTS 1700.7B Addendum 1) 213.1 (4), 213.1 (7);	☑ CATASTROPHIC ☐ CRITICAL ☐ MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Defective components, wires or insulation coupled with inadequate bonding/grounding.	(1) Bonding and grounding in accordance with SSP 30245 (MILB-5087 amended) and SSP 30240.	(1) Testing of bonding and grounding per SSP 30245 (MILB 5087 amended) and SSP 30240.		TBD
(2) Exposed terminals or high voltage accessible to the crew during operations.	(2a) High voltages will be inaccessible to crew during normal operations.	(2a) Design review of drawings and inspection of as-built equipment.		
	(2b) Interlocks will be provided to remove power when operations require access to areas of exposure.	(2b) Test of interlocks.		

DETECTION AND WARNING METHOD:	REMARKS:
None	Note to PED: Provide schematics of HV sources, power switches and interlocks, and identify voltage potential(s).

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Ignition Sources (Electrical Wiring)

HAZARD ID NO: G-2

SUBSYSTEM: Electrical

HAZARDOUS CONDITION DESCRIPTION: Overheating of electrical wiring provides potential ignition source for flammable materials.

REVIEW: Phase 0

DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: Experiment Electrical Operations

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: None

REQUIREMENTS: SSP30652 (1700.7B Addendum 1) 213.1 (1), 213.1 (6)

HAZARD CATEGORY:
- [x] CATASTROPHIC
- [ ] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Wiring/fusing size inadequate to protect downstream wiring from overheating in the event of a short circuit or partial short circuit.	(1) Wiring/fusing designed/selected to protect downstream wiring in accordance with NSTS 18798A, Letter No. 21, Protection of Power Distribution Circuits.	(1) Analysis of circuits to verify conformance with NSTS 18798A.		TBD
	(2) Electrical hardware will be built in accordance with approved drawings.	(2) QA certification that as-built configuration is in accordance with design drawings.		

DETECTION AND WARNING METHOD: Caution and Warning System for Fire Detection

REMARKS: Note to PED: Attach simplified electrical schematic showing protective device type, rating (amps), and wire size (AWG). Document heaters,etc. on unique HR.

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION | PAYLOAD ACCOMMODATIONS MANAGER | SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Exposure of SSF or Other Payloads to Electromagnetic Interference (EMI)

HAZARD ID NO: G-3

SUBSYSTEM: Electrical

HAZARDOUS CONDITION DESCRIPTION: Conducted or radiated EMI can interfere with operations of SSF or other payloads.

REVIEW: Phase 0

DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: Experiment Electrical Operations

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: None

REQUIREMENTS: SSP30652 (NSTS 1700.7B, Addendum 1) 212.2; SSP 30237 (MIL-STD-461 amended) and SSP 30238

HAZARD CATEGORY:
- [ ] CATASTROPHIC
- [x] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Radiated or conducted EMI caused by electrical switching and/or equipment operation	Electrical, electromechanical, and electronic equipment will be designed for compliance with SSP 30237 and SSP 30238.	Test for radiated and conducted emissions in accordance with SSP 30237 and SSP 30238.		TBD

DETECTION AND WARNING METHOD: None

REMARKS: Note to PED: Assess experiments/facilities for radiated and conducted EMI susceptibility. If hazard identified, develop unique HR.

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION

PAYLOAD ACCOMMODATIONS MANAGER

SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)	**HAZARD TITLE:** Sharp Edges, Corners, Edges, and Protrusions	**HAZARD ID NO:** G-4
SUBSYSTEM: Human Factors	**HAZARDOUS CONDITION DESCRIPTION:** Injury to personnel by contact with sharp corners, edges, and protrusions.	**REVIEW:** Phase 0 **DATE REVISION:**
AFFECTED INCREMENT(S): TBD	**OPERATIONS:** Anytime crew is exposed to the payload hardware equipment.	**HAZARD STATUS:** ☑ OPEN ☐ CLOSED

MISSION PHASE: ☐ GROUND OPERATIONS ☐ LAUNCH/RETURN ☐ ON-ORBIT TRANSFER ☑ ON-ORBIT OPERATIONS	**CRITICAL INTERFACES:** None	**REQUIREMENTS:** SSP 30652 (NSTS 1700.7B Addendum 1) 221.1	**HAZARD CATEGORY:** ☐ CATASTROPHIC ☑ CRITICAL ☐ MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Hardware designed and/or manufactured with sharp edges, corners, protrusions, burrs, etc., coupled with crew contact.	Hardware will be designed to comply with the intent of NASA STD 3000, paragraphs 6.3.3 and 14.1.3 (EVA)	(1) Drawing review of inclusion of requirement to remove sharp edges, burrs, corners, and protrusions or provide protective covers. (2) QA certification that as-built hardware conforms to approved drawings.		TBD

DETECTION AND WARNING METHOD: None	**REMARKS:** Note to PED: For planned EVA, this hazard report must be identified as catastrophic.

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
TBD	Toxic Offgassing Materials in Habitable Areas	G-5

SUBSYSTEM:	HAZARDOUS CONDITION DESCRIPTION:	REVIEW:
Materials	Offgassing of toxic constituents from materials used in habitable areas could cause temporary or permanent crew injury or illness.	Phase 0 DATE REVISION:

AFFECTED INCREMENT(S):	OPERATIONS:	HAZARD STATUS:
TBD	TBD	[√] OPEN [ ] CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
[ ] GROUND OPERATIONS [ ] LAUNCH/RETURN [ ] ON-ORBIT TRANSFER [√] ON-ORBIT OPERATIONS	None	SSP 30652 (NSTS 1700.7B Addendum 1), 209.3	[√] CATASTROPHIC [ ] CRITICAL [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Use of materials which offgas toxic substances or by-products in habitable areas.	(1) "A" or "K" rated materials will be selected from MSFC HDBK-527/JSC 09604 or a Materials Usage Agreement (MUA) will be submitted to TBD for approval by the Materials Review Board.	(1a) Approval by TBD Materials Review board of Materials Identification and Usage List (MIUL) and MUAs. (1b) Assemblies will be offgas tested in accordance with NHB 8060.1 and test data approved by TBD.		TBD
	(2) Equipment/hardware will be built in conformance with design drawings and approved materials list.	(2) QA certification that as-built configuration is in accordance with design drawing and approved materials lists.		

DETECTION AND WARNING METHOD:	REMARKS:
TBD	Note to PED: Rigorous material control to ensure acceptable offgassing characteristics are negotiable alternative to black box level testing.

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Use of Flammable Materials	G-6

SUBSYSTEM:	HAZARDOUS CONDITION DESCRIPTION:	REVIEW:
Materials	Use of flammable materials in close proximity to an ignition source can result in a fire.	Phase 0 DATE REVISION:

AFFECTED INCREMENT(S):	OPERATIONS:	HAZARD STATUS:
TBD	TBD	[√] OPEN [ ] CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
[ ] GROUND OPERATIONS [ ] LAUNCH/RETURN [ ] ON-ORBIT TRANSFER [√] ON-ORBIT OPERATIONS	None	SSP 30652 (NSTS 1700.7B Addendum 1), 209.2	[√] CATASTROPHIC [ ] CRITICAL [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Use of flammable materials in close proximity to an ignition source	(1) "A" rated materials will be selected from MSFC HDBK 527/JSC 09604, Table 2, or a Materials Usage Agreement (MUA) will be submitted to TBD for approval by the Materials Review Board.	(1a) Approval by TBD Materials Review Board of Materials Identification and Usage List (MIUL) and MUAs. (1b) Materials covered by MUAs will be tested in accordance with NHB 8060.1, and test data approved by TBD Materials Review Board (if required).		TBD
	(2) Equipment hardware will be built in accordance with design drawings and approved materials lists.	(2) A certification that as-built configuration is in accordance with design drawings and approved materials lists.		

DETECTION AND WARNING METHOD:	REMARKS:
SSF Caution and Warning System for fire detection.	Note to PED: When flammable materials are used in proximity to an ignition source, a propagation analysis will be performed.

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Structural Failure	G-7

SUBSYSTEM:	HAZARDOUS CONDITION DESCRIPTION:	REVIEW:
Structures	Failure of structural components or attachment hardware can result in unrestrained objects which can impact other equipment or personnel.	Phase 0 DATE REVISION:

AFFECTED INCREMENT(S):	OPERATIONS:	HAZARD STATUS:
TBD	All	[√] OPEN [ ] CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
[ ] GROUND OPERATIONS [ ] LAUNCH/RETURN [√] ON-ORBIT TRANSFER [√] ON-ORBIT OPERATIONS	TBD	SSP 30652 (NSTS 1700.7B Addendum 1), 208.1b, 208.3; NSTS 1700.7B, 208.1, 208.2	[√] CATASTROPHIC [ ] CRITICAL [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Structural components lack strength to withstand launch or landing loads, on-orbit environments, or failure due to pre-existing flaws.	(1a) All metallic safety-critical structures design based on factors of safety 2.0 ultimate and 1.25 yield on untested structures, or 1.4 ultimate and 1.1 yield when qualified by static load tests with no negative margins of safety for worst-case mission-induced loads. (1b) Design based on fracture control procedures for safety-critical structures per NHB 8071.1.	(1a) Structural analysis to verify positive margins of safety and static load tests for safety factors less than 2.0 ultimate. Analysis based on verified math models. (1b) TBD Fracture Control Board approval of Fracture Control Plan and analysis (including NDE).		TBD
(2) Use of materials subject to stress corrosion cracking.	(2) Materials selected in accordance with MSFC-SPEC-522B, Table 1, or a Materials Usage Agreement (MUA) will be submitted for approval.	(2) Approval of metallic materials list and MUAs by TBD.		
(3) Manufacturing defects	(3) Safety-critical structures built in accordance with approved drawings and materials lists.	(3) QA certification that as-built hardware is in accordance with approved drawings and materials lists.		

DETECTION AND WARNING METHOD:	REMARKS:
None	

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Release of Hazardous Sample Material into Habitable Area (Processing Phase)

HAZARD ID NO: U-1

SUBSYSTEM: Materials

HAZARDOUS CONDITION DESCRIPTION: Release of toxic sample material into the habitable area of the US Lab may result in injury or illness to the crew.

REVIEW: Phase 0
DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: Processing Phase

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: SSF Vacuum Exhaust System

REQUIREMENTS: SSP 30652 (NSTS 1700.7B Addendum 1) 202.6a, 202.6b, 202.6c; 209.1, 209.1b, 209.4

HAZARD CATEGORY:
- [x] CATASTROPHIC
- [ ] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Loss of containment during the processing phase due to temperature and pressure exceedances.	(1) Toxic sample materials enclosed in a sealed ampoule/cartridge (depending on design, could be single or double levels of containment). (2) Sample ampoule/cartridge contained in a sealed container designed to pressure vessel criteria. (3) Sealed container maintained at negative pressure differential relative to US Lab cabin. (4) Control of processing temperatures.			

DETECTION AND WARNING METHOD: TBD

REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION | PAYLOAD ACCOMMODATIONS MANAGER | SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Release of Hazardous Sample Material into Habitable Area (Pre/Post Processing Phase)

HAZARD ID NO: U-2

SUBSYSTEM: Materials

HAZARDOUS CONDITION DESCRIPTION: Release of toxic sample and/or furnace material into the US Lab may result in injury or illness to the crew.

REVIEW: Phase 0
DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: Pre/Post Processing Phase

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: SSF Vacuum Exhaust System

REQUIREMENTS: SSP 30652 (NSTS 1700.7B Addendum 1) 202.6a, 202.6c; 209.1b; 208.1b

HAZARD CATEGORY:
- [x] CATASTROPHIC
- [ ] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Pre-Processing Phase: a. Launch loads damage SACA resulting in loss of containment of sample materials. b. Launch loads damage furnace resulting in loss of containment of hazardous furnace materials (e.g., beryllium). 2. Post-Processing Phase: a. Loss of containment due to crew mishandling of SACA's or improperly handling ruptured SACA. b. Loss of containment of furnace hazardous materials (BeO dust generated) during processing.	(1) Pre-Processing Phase: 1a1 and 1b1 - Design for worst case launch loads with positive margins of safety. b2 - Use of contingency containment devices, such as a glovebox, if furnace is to be opened to US Lab environment. 2. Post-Processing Phase: 2a1 and 2b - Use of contingency containment device such as a glovebox. 2a2 - Training and use of approved procedures.			

DETECTION AND WARNING METHOD: TBD

REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Failure of Pressure Vessels, Lines and Fittings, or Components	U-3
SUBSYSTEM: Pressure	**HAZARDOUS CONDITION DESCRIPTION:** Rupture of pressurized equipment can result in fragments impacting personnel or other equipment resulting in injury/death or damage.	**REVIEW:** Phase 0 **DATE REVISION:**
AFFECTED INCREMENT(S): TBD	**OPERATIONS:** All operations involving pressured hardware	**HAZARD STATUS:** ☑ OPEN ☐ CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
☐ GROUND OPERATIONS ☐ LAUNCH/RETURN ☐ ON-ORBIT TRANSFER ☑ ON-ORBIT OPERATIONS	TBD	SSP 30652 (NSTS 1700.7B Addendum 1) 208.4	☑ CATASTROPHIC ☐ CRITICAL ☐ MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Inadequate structural design of pressure vessel, lines, fittings, and other components.	(1a) Pressure vessels. Design in accordance with MIL-STD-1522A as modified by para. 208.4a. Safety factor ≥ 2.0. (1b) Lines and fittings. Design safety factors in accordance with para. 208.4c. (1c) Other pressure components. Design safety factors ≥ 2.5 ultimate.	(1a) Design review. Stress analysis. Leak before burst analysis. Fracture mechanics analysis/NDE inspection (if required per NHB 8070.1). Approved by TBD Fracture Control Board. Certified test results (proof, burst, cycles as applicable). (1b and 1c) Design review. Stress analysis showing positive margins of safety. Proof test to 1.5 x MDP.		TBD
(2) Use of stress corrosion susceptible materials.	(2) Material selection in accordance with MSFC-SPEC-522A.	(2) Materials lists/MUAs approval by TBD Materials Review Board.		
(3) Failure of pressure system components.	(3) Where pressure regulators, relief valves, etc., are used for pressure control, they will be two-fault tolerant for exceeding system MDP.	(3) Design review		
(4) Manufacturing	(4) As-built hardware in accordance with approved design drawings and materials lists.	(4) QA certification.		

DETECTION AND WARNING METHOD:	REMARKS:
None	

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Corrosive Material Released in US Lab Vacuum Exhaust System

HAZARD ID NO: U-4

SUBSYSTEM: Materials

HAZARDOUS CONDITION DESCRIPTION: Corrosive material in US Lab Vacuum Exhaust System can result in SSF damage, possible crew injury/illness and contamination of SSF outer envelope.

REVIEW: Phase 0

DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: TBD

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: SSF Vacuum Exhaust System

REQUIREMENTS: SSP 30652 (NSTS 1700.7B Addendum 1) 202.6a, 209.1, 209.4

HAZARD CATEGORY:
- [x] CATASTROPHIC
- [ ] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Sample material containment failure followed by venting into SSF Vacuum Exhaust System.	(1) Sample ampoule/cartridges shall be designed for one or two levels of containment for the expected operating environment. (2) Temperature control of furnace heating (3) Use of filters and contamination monitoring of furnace exhaust products coupled with capability to shut down and seal off furnaces safely.			

DETECTION AND WARNING METHOD: TBD

REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION

PAYLOAD ACCOMMODATIONS MANAGER

SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Exposure of Crew to Frangible Materials

HAZARD ID NO: U-5

SUBSYSTEM: Human Factors

HAZARDOUS CONDITION DESCRIPTION: Breakage/Fracture of frangible materials may result in contamination of habitable areas with particulates causing possible severe injury to the crew.

REVIEW: Phase 0

DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: TBD

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [x] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: None

REQUIREMENTS: SSP 30652 (NSTS 1700.7B Addendum 1) 206, 215

HAZARD CATEGORY:
- [x] CATASTROPHIC
- [ ] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Inadequate design of frangible materials for use environment (2) Improper handling of equipment containing frangible materials	(1) Design for containment based on intended use. Frangible items will be enclosed in cases, housings, etc., covered by shields, and/or provided with protective caps. (2a) Proper handling covered in crew procedures (2b) Crew training	(1a) Design review (1b) Containment analyses (1c) Tests (vibration, impact) (2a) Review of procedures (2b) Review of training		TBD

DETECTION AND WARNING METHOD: None

REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION

PAYLOAD ACCOMMODATIONS MANAGER

SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT: Space Station Furnace Facility (SSFF)

HAZARD TITLE: Hazardous Touch Temperature

HAZARD ID NO: U-6

SUBSYSTEM: Human Factors

HAZARDOUS CONDITION DESCRIPTION: Temperatures of equipment accessible to the crew exceeds touch temperature levels (>45°C/113°F) or (<4°C/40°F)

REVIEW: Phase 0
DATE REVISION:

AFFECTED INCREMENT(S): TBD

OPERATIONS: During TBD equipment operations

HAZARD STATUS:
- [x] OPEN
- [ ] CLOSED

MISSION PHASE:
- [ ] GROUND OPERATIONS
- [ ] LAUNCH/RETURN
- [ ] ON-ORBIT TRANSFER
- [x] ON-ORBIT OPERATIONS

CRITICAL INTERFACES: SSF Air and water cooling loops; crew

REQUIREMENTS: SSP 30652 (NSTS 1700.7B Addendum 1) 221.5

HAZARD CATEGORY:
- [ ] CATASTROPHIC
- [x] CRITICAL
- [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Crew exposure to high or low temperature surfaces due to:				TBD
(1) Inadequate cooling or heating	(1a) and (2a) Equipment surfaces subject to crew contact shall be designed (e.g., insulated, heated, or cooled) to preclude temperature exceedances.	(1a) and (2a) Design review, analysis and tests (including loss of cooling and/or heating)		
(2) Inadequate insulation	(1b) and (2b) Guards, shields, or sensitive warning labels to preclude crew contact.	(1b) and (2b) QA certification that as-built hardware conforms to approved drawings.		
(3) Inadequate on-orbit handling procedures	(3) Procedures to include caution notes notifying crew of potential touch temperature exceedances	(3) Review of procedures		

DETECTION AND WARNING METHOD: TBD

REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION | PAYLOAD ACCOMMODATIONS MANAGER | SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

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PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Structural Failure of Rotating Devices	U-8
SUBSYSTEM: Structures	**HAZARDOUS CONDITION DESCRIPTION:** Structural failure of rotating devices could result in the devices fragmenting, possibly resulting in equipment damage or crew injury.	**REVIEW:** Phase 0 **DATE REVISION:**
AFFECTED INCREMENT(S): TBD	**OPERATIONS:**	**HAZARD STATUS:** ☑ OPEN ☐ CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
☐ GROUND OPERATIONS ☐ LAUNCH/RETURN ☐ ON-ORBIT TRANSFER ☑ ON-ORBIT OPERATIONS	None	SSP 30652 (NSTS 1700.7B Addendum 1), 206, 208.1b, 221.2, 221.3	☑ CATASTROPHIC ☐ CRITICAL ☐ MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
(1) Inadequate structural design	(1a) Rotating devices designed to withstand worst-case loads, including fracture control requirements per SSP 30558/NHB 8071.1.	(1) Structural analysis (stress, fracture mechanics as required)		TBD
	(1b) Rotating devices enclosed and shielded with structures of sufficient integrity to contain fragments.	(1b) Analysis of structural strength of containment.		
	(1c) Motors operated within manufacturers stated operating range.	(1c) Design review.		
(2) Runaway/over-speed motors	(2a) Motors limited by design to preclude runaway.	(2) Analysis of motor power, speed, speed-limiting characteristics.		

DETECTION AND WARNING METHOD:	REMARKS:
None	

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION	PAYLOAD ACCOMMODATIONS MANAGER	SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

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PAYLOAD OR INCREMENT PAYLOAD COMPLEMENT:	HAZARD TITLE:	HAZARD ID NO:
Space Station Furnace Facility (SSFF)	Loss of Cooling	U-10

SUBSYSTEM:	HAZARDOUS CONDITION DESCRIPTION:	REVIEW:
Environmental Control	Loss of coolant flow during heat producing operations resulting in fire, toxic offgassing and/or explosion.	Phase 0 DATE REVISION:

AFFECTED INCREMENT(S):	OPERATIONS:	HAZARD STATUS:
TBD	Processing Phase	[√] OPEN [ ] CLOSED

MISSION PHASE:	CRITICAL INTERFACES:	REQUIREMENTS:	HAZARD CATEGORY:
[ ] GROUND OPERATIONS [ ] LAUNCH/RETURN [ ] ON-ORBIT TRANSFER [√] ON-ORBIT OPERATIONS	SSF Environment Control System	SSP 30652 (NSTS 1700.7B Addendum 1) 206	[√] CATASTROPHIC [ ] CRITICAL [ ] MARGINAL

HAZARD CAUSE:	HAZARD CONTROL METHODS: (Potentials)	METHOD FOR VERIFICATION OF CONTROL:	STATUS:	REFERENCES:
Loss of coolant flow to SSFF during heat producing operations.	Design of furnaces, containment apparatus and avionics boxes shall either be fail-safe, or in combination with Thermal Control System (TCS) be two-failure tolerant for loss of cooling. - "Loss of coolant" flow sensors cause power to be removed - Avionics boxes fail-safe - Accumulator in water loop to preclude over-pressure of lines			

DETECTION AND WARNING METHOD:	REMARKS:

APPROVAL:

PAYLOAD DEVELOPER ORGANIZATION

PAYLOAD ACCOMMODATIONS MANAGER

SPACE STATION FREEDOM PAYLOAD SAFETY PANEL

SSFF CONFIGURATION AND MAINTENANCE CONTROL CONCEPT

1.0 PURPOSE

This document outlines a combined configuration and maintenance control concept for use in the development of detailed plans during on-orbit operation of the SSFF. Configuration control is defined as "The systematic definition, evaluation, coordination, disposition, and accounting of each proposed change, deviation or waiver and the implementation of each approved change in the configuration of a program after formal establishment of the configuration identification". Maintenance control within the context of this concept, involves considerations associated with changes to SSFF equipment that are of an immediate nature such that the formal configuration control process will not accommodate them in a timely enough manner. This concept should serve as an aid during the development of Configuration and Maintenance Control Plans, such that the following results will be attained: 1) All personnel concerned with the SSFF or any of it's subsystems, are working with the latest information and current baseline; 2) all proposed changes are assessed for technical, safety, reliability, schedule, and resource impacts; and 3) the system configuration retains traceability throughout the on-orbit experiment and/or mission phases.

2.0 BACKGROUND

System Configuration is maintained through several processes: (1) Configuration Identification; (2) Configuration Change Control; (3) Configuration Change Status Accounting; (4) Configuration Audits; (5) Maintenance Control Documentation; and (6) Recovery of Lost Configuration Control.

2.1 CONFIGURATION IDENTIFICATION

During SSFF conceptual stages, the basic subsystems and components of the system will be identified. Baseline requirements for these subsystems and components will then be developed. Baselines are identified by specifications, procedures, and drawings as approved by the respective program/project manager, at a specific time during its life cycle. Baselines, plus approved changes, identify the current approved configuration. The Baseline will identify all engineering drawings, specifications, and requirements documentation relating to the specific system, subsystem, or component.

2.2 CONFIGURATION CHANGE CONTROL

The baseline will be maintained by procedures that prohibit any revision unless approved by a formal change control process. All proposed changes to the system design, replacement/repair of any system component, or change in experiment hardware will normally begin with submission of a Engineering Change Proposal (ECP) (see Figures 1 and 2). Finalized ECP's will be prepared and sent to Configuration Management (CM) for entry into an automated tracking system. The Configuration Status Report (CSR) will reflect all ECP's pending evaluation/disposition. CM will route the ECP to the appropriate Engineering discipline for evaluation of the proposed change. Engineering assessments and recommendations will be returned to CM for distribution to affected agencies and all members of the Configuration Control Board (CCB) at least three days prior to the next CCB meeting. A formal CCB charter will establish the guidelines for dispositioning the ECP. The CCB will include multiple technical discipline personnel familiar with the system and related subsystems. Each technical member of the CCB will evaluate ECPs within his/her area of technical expertise. Engineering disciplines and Project Management will be responsible for evaluating design trade studies. When practical the ECP initiator, or

designated representative, will attend the CCB meetings and provide additional input concerning specific ECPs.

The CCB will perform the following functions:

a. Review the status of each open ECP.
b. Request additional analysis or action from Engineering and/or the initiator.
c. Disposition all ECPs.
d. Direct the appropriate Configuration change implementation as:
   1) An on-orbit Flight Crew modification;
   2) A replacement of Orbital Replacement Unit (ORU);
   3) A modification after system or components have completed flight.
e. Document all board dispositioned ECPs on CCB Directives (CCBDs).

Configuration change control will publish agendas, minutes, and directives to ensure that changes receive appropriate evaluation by technical and management discipline and that only CCB-approved changes are incorporated into the baseline documentation. Configuration change control will also maintain and publish the Configuration Status and Accounting Report (CSAR). Inspections of hardware will be performed to ensure final as built configuration.

After CCB disposition, the ECP will be returned to CM for implementation or closure. CM will update the tracking system and prepare the necessary documentation for the next step in the processing of the ECP. Work Orders (WO) will be prepared by the appropriate activity for all approved ECP's. Rejected ECP's will be routed back to the initiator. A revised ECP may be prepared and returned to CM for reconsideration. CM will then either reroute the amended ECP to the appropriate Engineering discipline, the CCB, or return to the initiator for additional actions.

A duplicate, functional SSFF system maintained on Earth will provide technical personnel with a working model of the on-orbit system. The on-Earth system will be used for reverification efforts, system testing, training, demonstration, and problem investigation. Configuration changes will be completed and evaluated with the on-Earth system prior to implementation on-orbit. Additional details are contained in the SSFF Functional Verification Concept.

2.3 CONFIGURATION CHANGE STATUS ACCOUNTING

CM will maintain a data base of the established baseline, approved changes, and ECP's pending evaluation and dispositioning. Reports of implemented and pending changes will be provided to developmental and operational organizations. A master system configuration document will be developed. This document will provide traceability to all implemented and pending ECP's. The CSAR will be compatible with existing NASA requirements and data processing capabilities.

2.4 CONFIGURATION AUDITS

Audits will be conducted during Configuration Control activities to evaluate the design, progress, approach and status of design, and to verify that SSFF performance complies with specifications. ECPs may be generated as a result of audits, to ensure that baseline documentation agrees with "as built" configurations.

2.5 MAINTENANCE CONTROL DOCUMENTATION

Equipment changes of an immediate nature would necessarily fall within the bounds of a maintenance procedure contained in a maintenance control plan. These changes would be documented as results of Field Engineering Changes (FECs) (see Figures 1 and 3). Normally such changes will involve Temporary Changes (TCs), Parts Replacements (PRs), and Part Repair with no Replacements (RNRs) (see Figures 4, 5, and 6). In all cases the appropriate configuration control documentation will be updated following execution of an approved FEC.

2.5.1 TEMPORARY CHANGE (TC)

TCs are implemented when hardware is to be replaced, and a temporary repair or work-around is necessary to accommodate mission objectives. The process shown in Figure 4 will result both in authorization for the Flight Crew to perform the temporary modification/repair, as well as direction for the appropriate hardware group to fabricate replacement hardware. The Change Authority can disapprove and close a TC, or change the category either to a PR, or a RNR, or return the TC to the originator for reconsideration and resubmission.

2.5.2 PART REPLACEMENT (PR)

PRs are directed/required when hardware wear/failure dictates its replacement. If the PR is approved, the Change Authority normally will determine whether the replacement will take place on-orbit or after the Flight Unit has been returned to Earth. The PR will remain open until completion of the hardware replacement. The Change Authority can disapprove and close the PR, or change the category either to a TC, or a RNR, or return the PR to the originator for reconsideration and resubmission (see Figure 5).

2.5.3 REPAIR NOT REPLACE (RNR)

RNRs address hardware needing repair, but not replacement. If the RNR is approved, the Change Authority will determine whether the repair will take place On-orbit or after the Flight Unit has been returned to Earth. The RNR will remain open until the repair has been completed. The Change Authority can disapprove and close the RNR, or change the category either to a TC, or a PR, or return the RNR to the originator for reconsideration and resubmission (see Figure 6).

2.6 RECOVERY OF LOST CONFIGURATION CONTROL

Some maintenance operations conducted on-orbit may result in a SSFF configuration that no longer matches the baseline documentation -- configuration control or traceability has effectively been "lost". In such cases configuration control may be recovered through use of an equipment log book, or similar document, maintained by the crew while conducting on-orbit operations. This document should serve to identify discrepancies between actual and baseline SSFF/subsystem/experiment configurations. CM will process a priority ECP to correct and update the CAS and configuration documentation when necessary.

3.0 REFERENCE DOCUMENTS

Document Number	Title
320PLN0004 6 September 1991	Configuration Management Plan for Space Station Furnace Facility
MM8040.12A	Standard Contractor Configuration Management Requirements, MSFC Programs

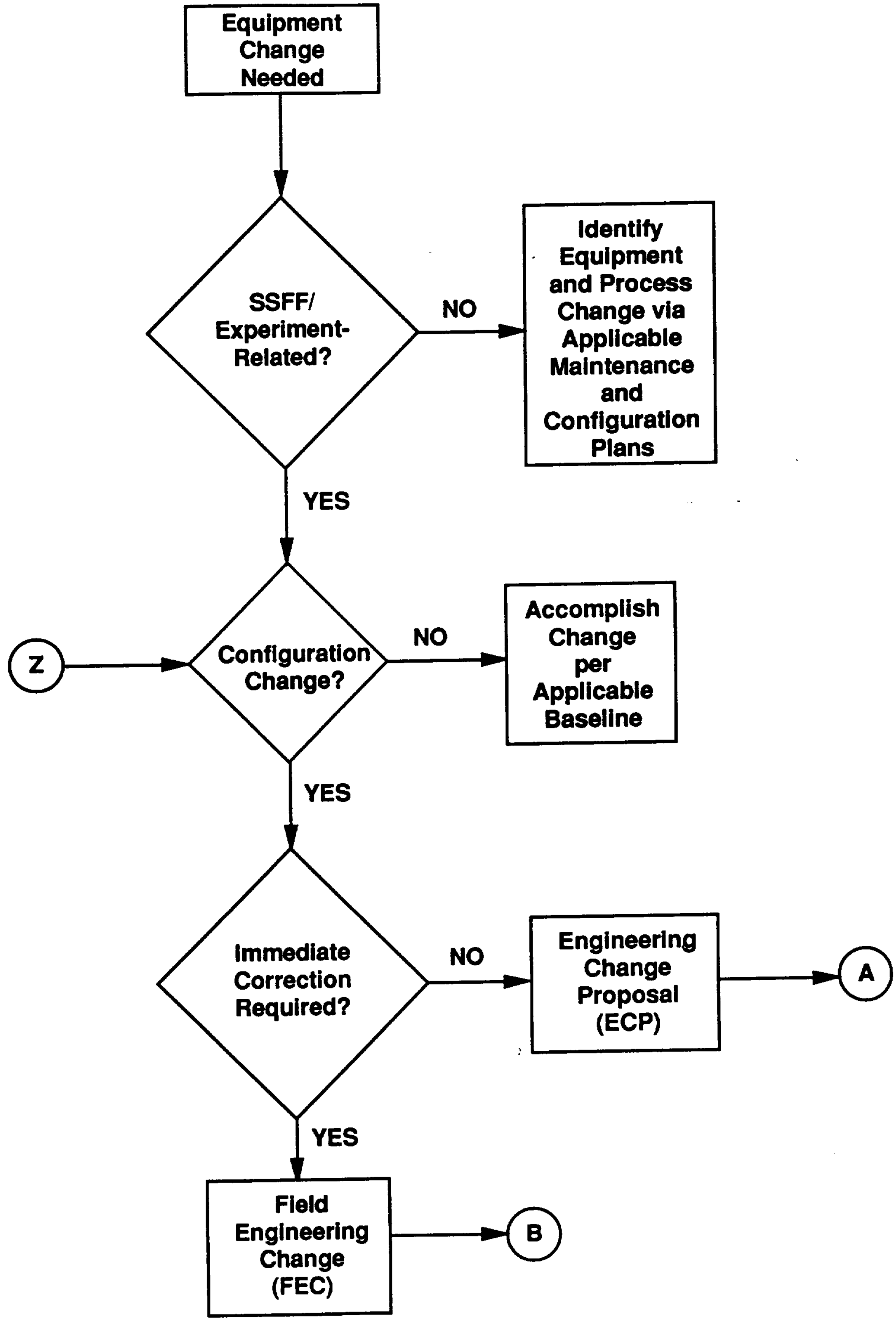


FIGURE 1. SSFF CONFIGURATION/MAINTENANCE CONTROL PROCESS

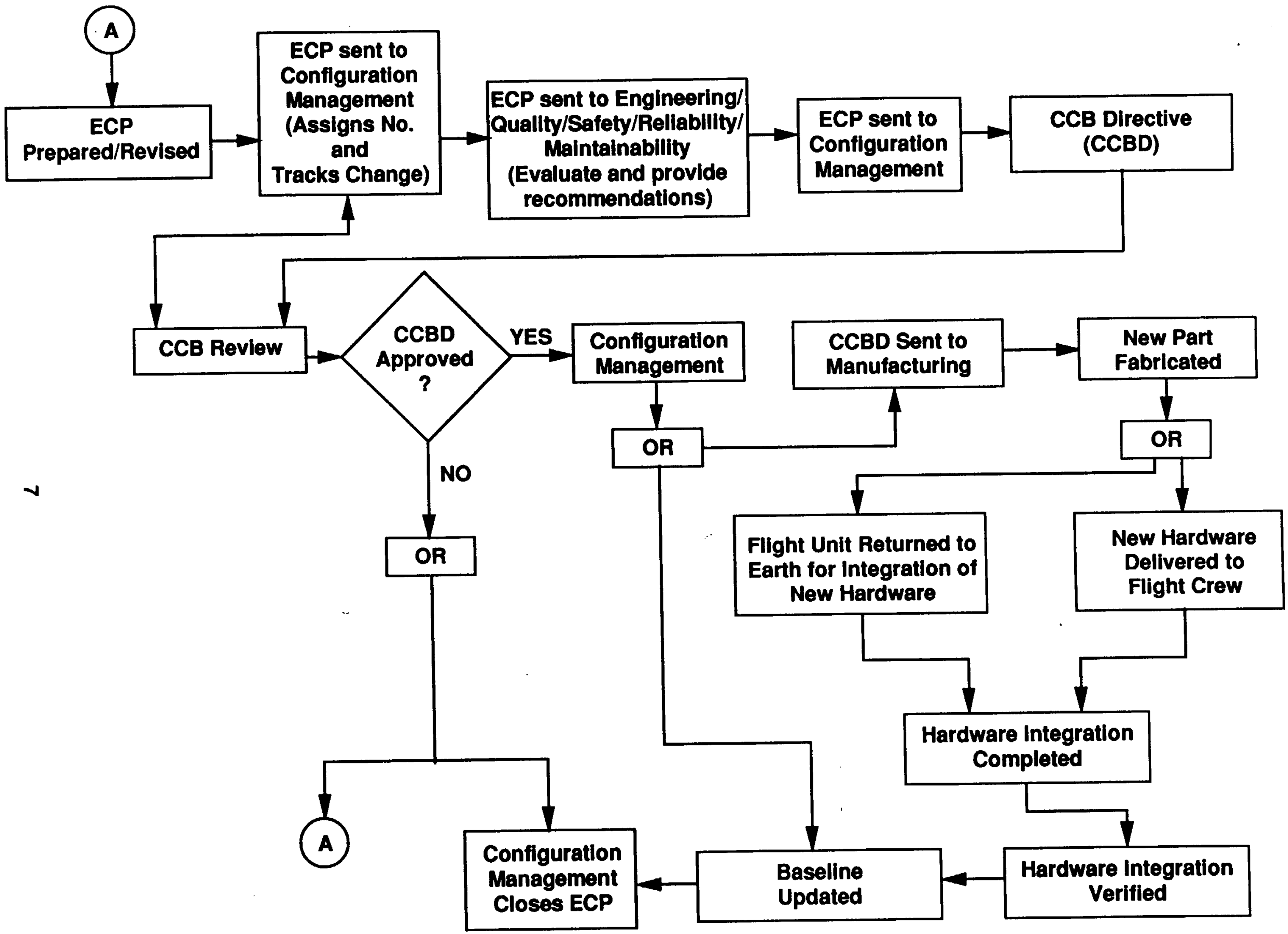


FIGURE 2. ECP PROCESS FLOW

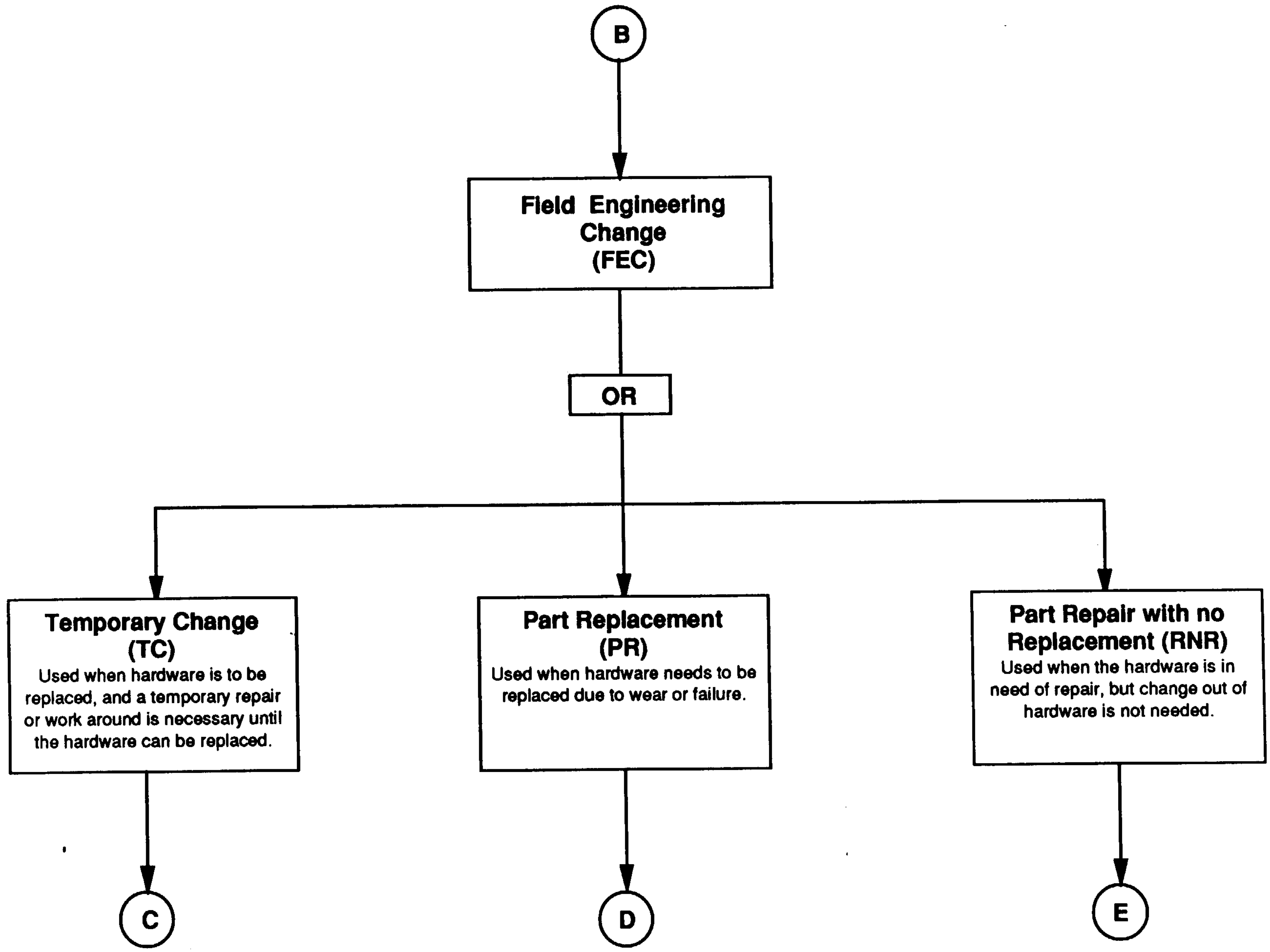


FIGURE 3. FIELD ENGINEERING CHANGE PROCESS

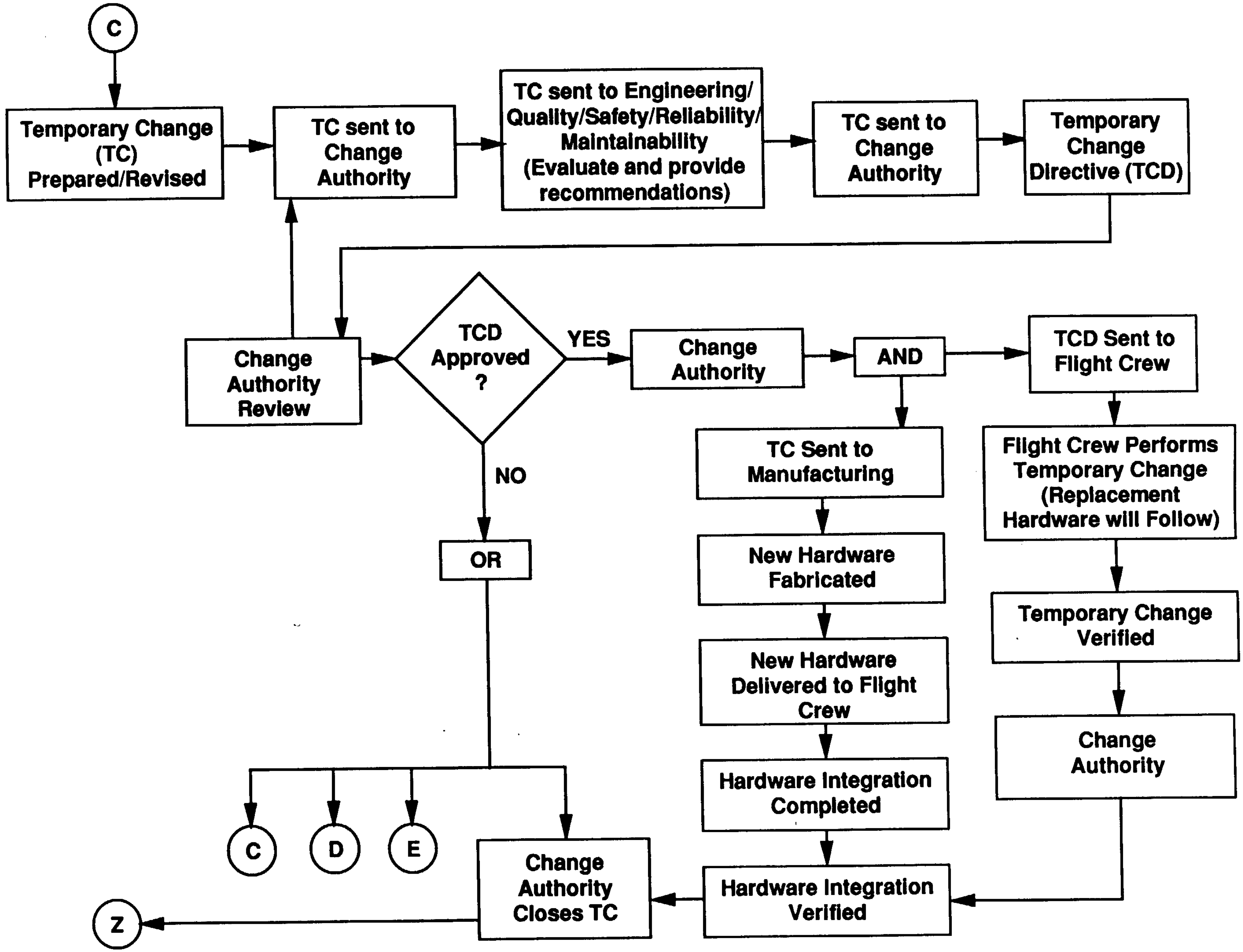


FIGURE 4. TEMPORARY CHANGE PROCESS FLOW

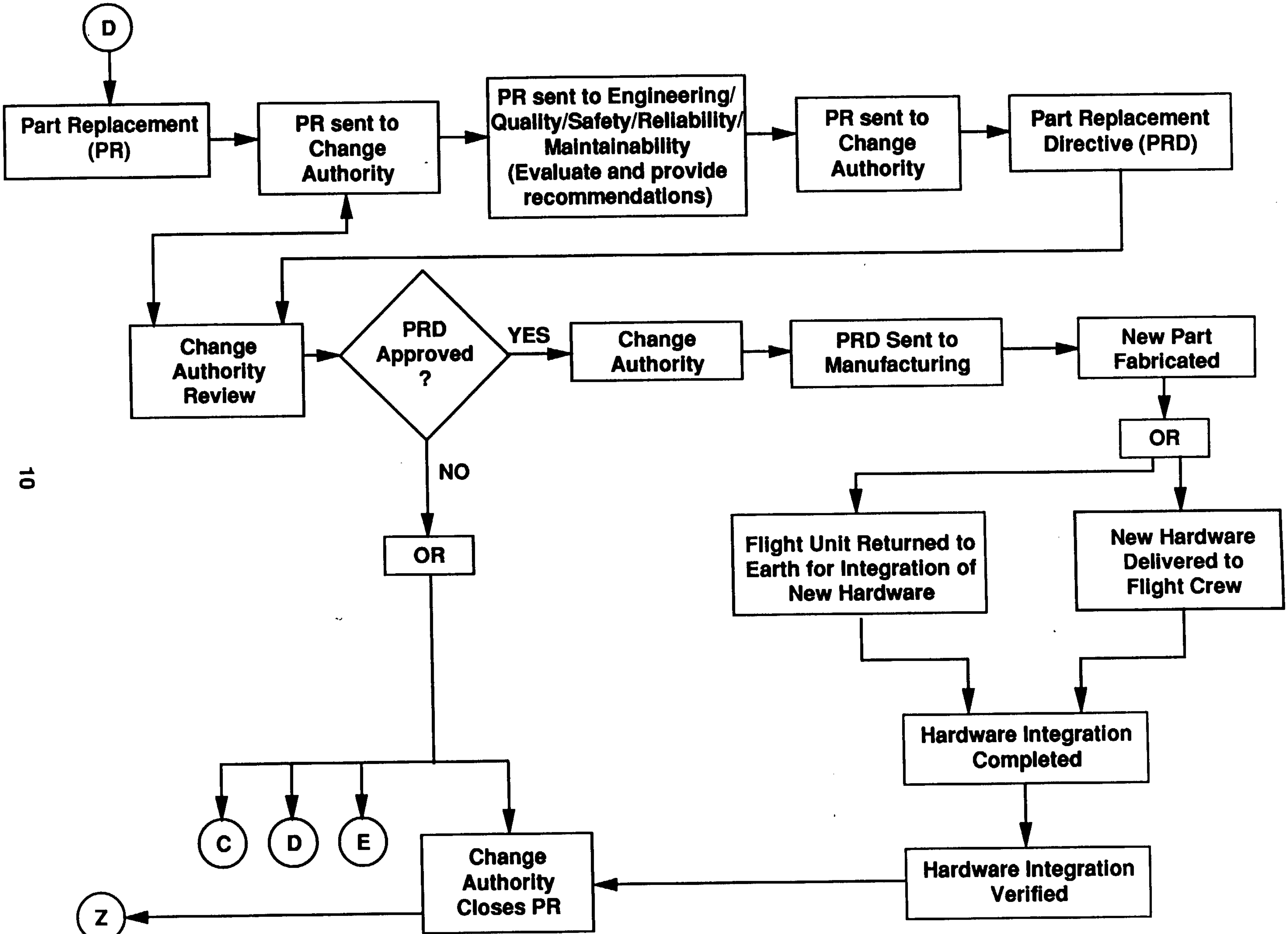


FIGURE 5. PART REPLACEMENT PROCESS FLOW

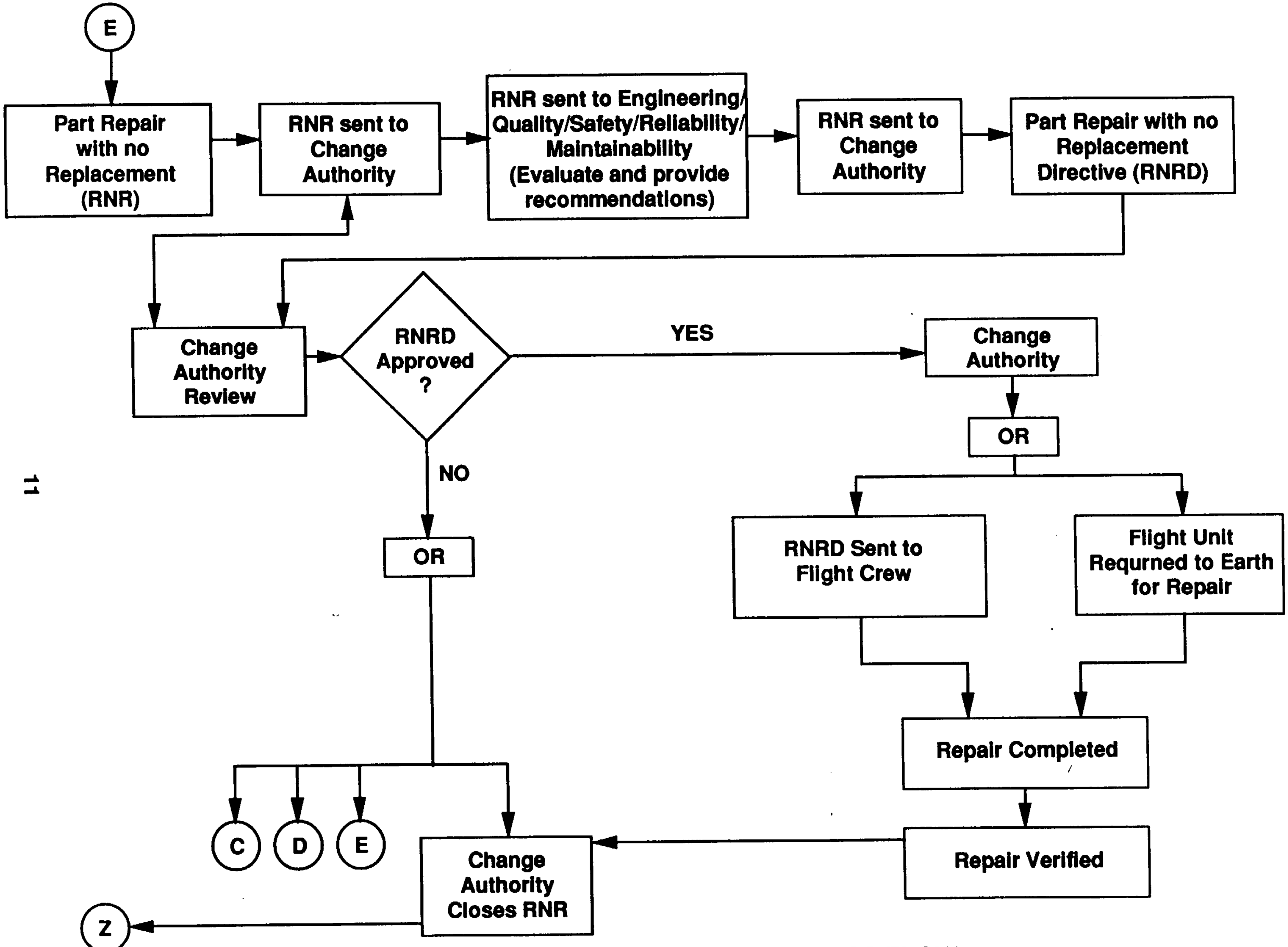


FIGURE 6. REPLACE NOT REPAIR PROCESS FLOW

SSFF SAFETY VERIFICATION CONCEPT

1.0 PURPOSE

This document outlines a safety verification program concept for on-orbit reconfigured hardware or software for the Space Station Furnace Facility (SSFF). The SSFF will fall under the jurisdiction of three (3) safety organizations: Kennedy Space Center's Payload Ground Safety Review Panel (PGSRP) will be responsible for all pre and post flight ground processing; the Space Shuttle Program's Payload Safety Review Panel (PSRP) at Johnson Space Center will be responsible for hardware and operational safety during transportation to and from SSF via the Space Shuttle, and the Space Station Freedom Program Office (SSFPO) Payload Safety Panel (PSP) at Reston, Virginia, will be responsible for safety of on-orbit operations aboard the SSF. The safety verification program for SSFF will ensure that on-orbit reconfigured or refurbished SSFF components, systems, and subsystems do not pose an unacceptable risk to personnel, the SSF, Space Shuttle, other payloads, or ground processing facilities and equipment

2.0 BACKGROUND

As the Space Station Freedom Program (SSFP) matures, it will become necessary to implement plans for safety reverification of recycled or reconfigured payloads and payload components. SSFP 30595, Space Station Freedom Payload Safety Review Process provides for safety reviews during payload concept development, preliminary design, final design, increment integration and planned on-orbit operations. The safety verification program will include on-orbit changes to the previously approved payload design, configuration and on-orbit operations, and ensure that hazards associated with such changes are properly identified and evaluated. Safety reviews are accomplished within the framework provided by the Space Station Freedom (SSF) Payload Safety Review Process (See Figure 1).

3.0 SSFF SAFETY VERIFICATION

On-orbit configuration changes may be planned or unplanned depending on mission requirements and situations. All planned configuration changes will be reviewed and approved through the SSFP 30595, Safety Review Process prior to flight and will enter the review process at the Phase II stage. This will include an Increment Phase B Review. All unplanned configuration changes will be coordinated with and approved by the appropriate payload safety panel(s) prior to implementation. An Increment Phase C Review will be required, except in the case of changes of a nature that real-time safety verification is required.

3.1 INCREMENT PHASE C SAFETY REVIEW REQUIREMENTS

The safety data packages for series, reflown, and on-orbit reconfigured SSFF payloads and/or components will satisfy the Increment Phase C data requirements (See Figure 1). The following data items will be submitted for review and consideration by the appropriate payload safety panel(s).

a. An assessment of each SSFF payload component to indicate whether or not the proposed use is the same as that previously analyzed and documented.
b. Hazard reports generated or revised to include new data and to indicate open/closed status.
c. A review and reevaluation of any previous noncompliances reports.

d. A report concerning life cycle limits for critical and limited life SSFF components.
e. A description of maintenance, structural inspection and refurbishment activities for the hardware, and an assessment of safety impact.
f. A description of any software changes and an assessment of safety impact.
g. An updated listing of chemical, organisms, and radioisotopes with quantities and concentrations.
h. An assessment of failures and anomalies during previous SSFF usage, with corrective actions and status.
i. A new, signed Certification of SSFP Payload Safety Compliance (See Figure 2 and 3).

Table 1 contains a partial listing of hazard examples both for on-orbit (flight) as well as ground processing operations.

Close contact and cooperation with the appropriate payload safety panel(s) will be maintained during their review of the above items to facilitate formal safety reverification by the panel(s).

3.2 REAL-TIME SAFETY VERIFICATION

On-orbit safety verification and recertification of the SSFF payload may be required following unplanned operational changes, unplanned reconfigurations, all maintenance or service activities, and/or the occurrence of anomalies that have a potential safety impact. Unplanned operational changes and reconfigurations include hardware and software modifications, payload mission changes, and operational procedure revisions. Modifications will include resupply items such as material processing samples or furnaces whose design, materials or construction are different from those provided for operations in an otherwise previously verified and certified SSFF payload. On-orbit modifications will be verified to the original criteria on the ground to the maximum extent possible. SSFF Payload operations and activities will be terminated when constrained by safety-related verifications until closeout is finalized.

SSFF payloads remaining on SSF at the end of an increment must be reassessed for possible recertification of operations on the next increment. If there are no changes (i.e., design, operations, environment, etc.) recertification for the next increment may be attained by updating and resubmitting the original certification. For purposes of this discussion, the SSFF payload, integrated rack hardware, and interfaces which affect safety are included.

The POIC is responsible for coordinating all SSFF payload operations. The SSF PSP has delegated responsibility to the SSF PAI function to conduct the Phase D Safety Assessment (see SSP 30595) in support of the POIC. As part of this assessment, the POIC and PAI must evaluate all unplanned on-orbit operational changes, maintenance activities, etc., for safety implications. Whenever on-orbit safety verification and possibly recertification is under consideration, the POIC will coordinate with the PSP via the SSF PAI function's safety representative supporting the POIC before taking action. The PAI function will in turn have support available from the organization(s) having responsibility for the original SSFF design and operations verification and certification, including the payload developer.

At the completion of all on-orbit verification activities, the PAI safety representative will complete the Increment Payload Complement Verification Tracking Log and incorporate the Log into the Increment Safety Data files.

4.0 DEFINITIONS

Catastrophic Hazard - Any condition which may cause a permanent or fatal personnel injury, or loss of one of the following: The launch or servicing vehicle, manned base, any NSTS cargo element, the loss of which could result in the loss of the manned base; major ground facility; or critical support equipment..

Certificate of Safety Compliance - A formal written statement attesting that the payload is safe and that all safety requirements have been met and, if not, what waivers and deviations are applicable.

Component - A combination of parts, devices, and structure - usually self-contained - that performs a distinctive function in the operation of the overall equipment.

Critical Hazard - Any condition which may cause a serious personnel injury; severe occupational illness; loss of safety monitoring, emergency control function or an emergency system, or requires the use of emergency procedures; or involves major damage to one of the following: The launch or servicing vehicle, manned base, any NSTS cargo element, which could result in the loss of, or major damage to a major SSF element; on-orbit life sustaining function, a ground facility, or critical support equipment.

Deviation - Granted use or acceptance of a payload aspect which does not meet the specified requirements. The intent of the requirement should be satisfied and a comparable or higher degree of safety should be achieved.

Hazard - The presence of a potential risk situation caused by an unsafe act or condition. A condition or changing set of circumstances that presents a potential for adverse or harmful consequences; or the inherent characteristics of an activity, condition, or circumstance, which can produce adverse or harmful consequences.

Hazard Report (HR) - A report that documents the hazard title, description, causes, controls, verifications, and status of a hazard analysis for a specific potentially hazardous condition/situation.

Noncompliance Report - A report documenting a condition in which a requirement cannot be met. It is the report used to request a waiver or deviation.

Payload - Any equipment or material carried by the Space Shuttle or used on the SSF that is not considered part of the basic assemblage itself. It, therefore, includes items such as free-flying automated spacecraft, individual experiments or instruments, and increment dependent equipment. It also includes payload-provided GSE and systems and flight and ground systems software.

Payload Life - The period of time that a payload is expected to be operating. The SSF Safety Certification will be for the planned mission life of the payload or payload component. Modifications to payload missions, mission life, or configuration will be reviewed by the appropriate safety panel(s).

Safety - Freedom from those conditions that cause injury or death to personnel and damage or loss of equipment or property.

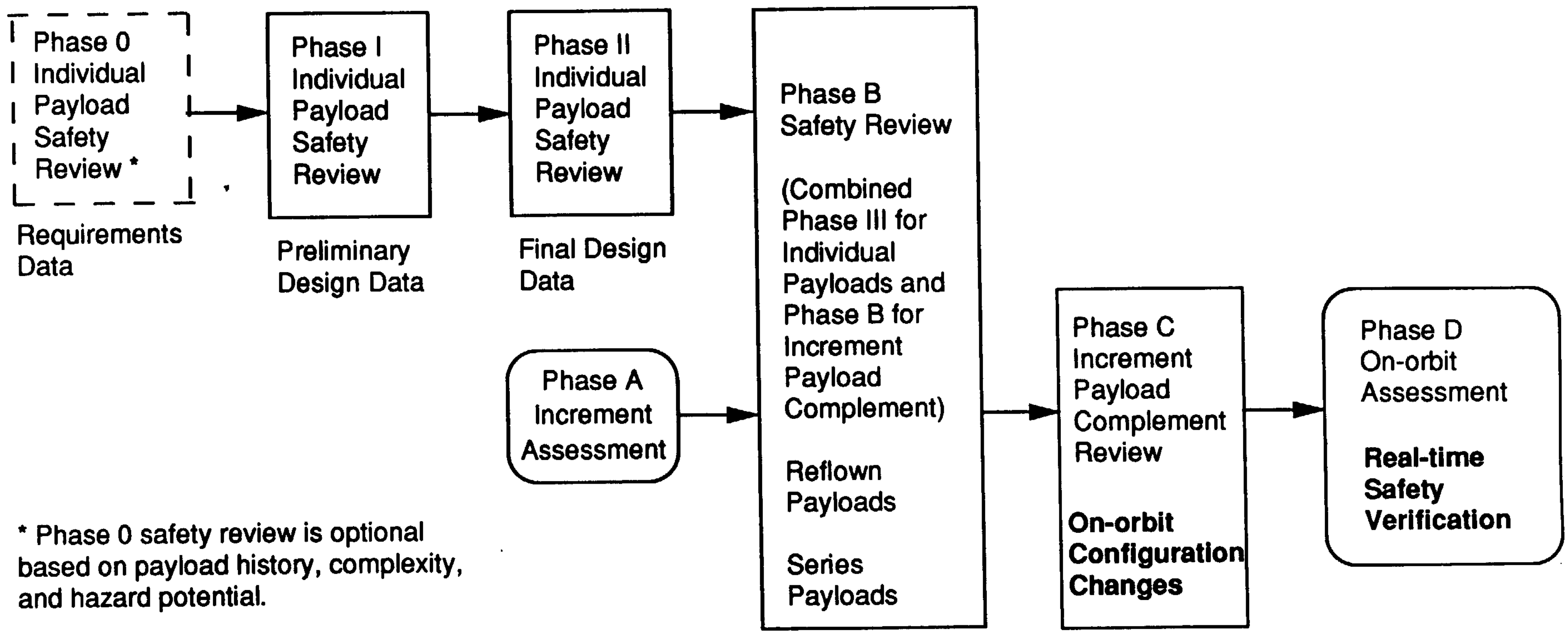
Safing - Actions which eliminate or control hazards.

Verification - Proof by inspection and/or analysis and/or test that the payload items in question perform to design specifications and does in fact control the identified hazard(s).

Waiver - Granted use or acceptance of a payload aspect which does not meet the specified requirements; a waiver is given or authorized for one mission only. Safety waivers will include acceptance of increased risk.

5.0 REFERENCE DOCUMENTS

KHB 1700.7A	Space Transportation System Payload Ground Safety Manual
NSTS 1700.7B	Safety Policy and Requirements for Payloads Using the Space Shuttle Transportation System
SSFP 30595	Space Station Freedom Payload Safety Review Process
SSP 30652 (NSTS 1700.7B Addendum 1)	SSFP Payload Safety Requirements for On-Orbit Operations



* Phase 0 safety review is optional based on payload history, complexity, and hazard potential.

FIGURE 1. SSF PAYLOAD SAFETY REVIEW PROCESS

CERTIFICATE OF SSFP PAYLOAD SAFETY COMPLIANCE

FOR

____

(Payload)

PAYLOAD DESIGN AND ON-ORBIT OPERATIONS.

THE PAYLOAD ORGANIZATION HEREBY CERTIFIES THAT:

(1) THE PAYLOAD IS SAFE.

(2) THE PAYLOAD COMPLIES WITH ALL APPLICABLE REQUIREMENTS OF SSP 30652.

LIST OF APPROVED WAIVERS / DEVIATIONS

APPROVAL:	DATE:
____________________ Payload Development Organization	____________
____________________ PAI Function	____________

FIGURE 2. CERTIFICATE OF PAYLOAD SAFETY COMPLIANCE

CERTIFICATE OF SSFP INCREMENT PAYLOAD COMPLEMENT SAFETY COMPLIANCE

FOR

____

(Increment)

INCREMENT DESIGN AND ON-ORBIT OPERATIONS

THE INCREMENT MANAGER HEREBY CERTIFIES THAT:

(1) THE INCREMENT PAYLOAD COMPLEMENT IS SAFE.

(2) THE INCREMENT PAYLOAD COMPLEMENT COMPLIES WITH ALL APPLICABLE REQUIREMENTS OF SSP 30652.

LIST OF APPROVED WAIVERS / DEVIATIONS

APPROVED: (Manager of the Increment)	DATE:

FIGURE 3. CERTIFICATE OF INCREMENT PAYLOAD SAFETY COMPLIANCE

TABLE 1. HAZARD EXAMPLES

GENERIC HAZARDS

TITLE	SAMPLE CONTROLS
Electrical Shock	Bonding and grounding per appl directives Bleed down circuitry if needed High voltage sources inaccessible to crew Interlocks provided where necessary Equipment grounded to facility ground (GSE)
Ignition Sources	Wiring/fusing selected to protect down-stream wiring in accord with appl directives Inaccessibility or isolation of high temperature surfaces/equipment to flammable equipment
EMI	Equipment designed such that conducted and radiated emissions do not exceed allowables
Sharp Corners/Edges/Protrusions	Hardware designed per appl requirements
Toxic Offgassing	Materials selected per appl directives Equipment built per approved materials lists Assemblies offgas tested Materials approved by appl office
Flammable Materials	Non-metallic materials meet appl requirements Materials approved by appl office
Structural Failure	Safety critical structure designed per appl criteria Design based on fracture control criteria Positive locking for threaded fasteners as neces Materials approved by appl office Safety critical structure built per approved dwgs GSE designed per appl requirements
Pressure Systems (Ground Ops)	Flight systems designed per appl criteria GSE pressure vessels designed to ASME GSE systems designed such that pressure cannot be trapped in any part of system without bleed capability GSE systems proof tested to 1.5 X MOP

UNIQUE HAZARDS

FLIGHT HAZARD EXAMPLES

Exposure of Crew to Broken Glass or Frangible Materials

Release of Toxic or Noxious Gas into Habitable Atmosphere

Containment of Flammable Fluids

Fragmentation or Failure of Rotating Equipment

Explosion/Rupture of Batteries

FLIGHT HAZARD EXAMPLES (CONT)

Contamination Because of Battery Electrolyte Leakage
Electrical Shock from Biomedical Instrumentation System
Improperly Stowed Equipment
Untethered Experiment Apparatus
Hazardous Touch Temperature
Exposure of Crew to Pathogenic Micro-Organisms
Containment of Stored Energy (Springs)
Explosion/Rupture of Pressure Systems
Contamination Because of Release of Mercury
Loss of Breathable Atmosphere
Use of Toxic Materials
Eye Injury as a Result of Exposure to Laser or Other High-Intensity Light
Overtemperature/Fire Resulting from Runaway Furnace or Heater
Loss of Cooling
Impediment to Emergency Egress
Use of Radioactive Materials
Containment of Toxic Experiment Samples
Loss of Safety Critical Equipment

GROUND HAZARD EXAMPLES

Use of Radioactive Materials
Release of Toxic Gases during Ground Operations
Use of Lasers/High-Intensity Light Causes Eye Damage
Oxygen Displacement in Confined Areas
Containment and Handling of Cryogenic Fluids
Use of Spark (Ignition) Sources in Equipment Adjacent to Orbiter or Propellant Systems
Explosion/Rupture of Batteries
Containment of Mercury
Handling/Operations using Biological Specimens
Use of Flammable Fluids during Ground Operations
Premature Actuation of Pyrotechnic Devices
Exposure of Ground Crew to Rotating Devices

SSFF FUNCTIONAL VERIFICATION CONCEPT

1.0 PURPOSE

The purpose of this concept is to present considerations for use during development of a detailed plan for the functional verification of the SSFF following changes to flight hardware during on-orbit operations aboard SSF.

2.0 BACKGROUND

The objective of the verification process is to ensure the acceptability and readiness of deliverable hardware and software for its intended use. The verification process will include:

- a. Support of design development.
- b. Confirmation that all system products meet established requirements.
- c. Confirmation that the performance of combined elements meets established requirements.

The goals of the SSFF verification program shall be compatible with the goals of the SSF verification program which are to:

- a. Integrate the hardware and software at the lowest level.
- b. Utilize SSF-supplied equipment for integration and testing.
- c. Utilize the same procedures and plans for verification from development to operational support.
- d. Use flight procedures that have been proven during ground test ops.

Tradeoffs between ground and on-orbit verification shall be made; however, as a minimum, mission or safety critical subsystems/systems shall be ground-verified prior to launch. Appendix I graphically shows the Verification/Reverification Process Flow. The on-orbit, first time verification of subsystems/systems shall be limited to subsystems/systems that are not mission or safety critical per SSP 30467, Volume 1, or verification that can only be performed on-orbit. Verifications shall be assessed by safety to ensure that the verification process does not result in hazards. Such verification shall require Space Station Control Board (SSCB) approval.

3.0 SSFF FUNCTIONAL VERIFICATION/REVERIFICATION

Functional verification of the integrated SSFF flight unit shall be accomplished by testing and/or demonstration, and shall be augmented by analyses/assessments and possibly inspections. Functional reverification of hardware/software shall be required as follows:

- a. Subsequent to modification of previously verified hardware or software.
- b. Following repair, configuration changes, or replacement of hardware/software.
- c. Subsequent to remate of previously verified mated connections or physical interfaces.

d. Prior to initiating hazardous or mission critical operations.
(Assess system risk. See Exhibit I. Class 1 is defined as crew/vehicle critical systems. Class 2 is defined as mission (payload) critical systems. Class 3 is defined as support systems.)
e. Following the incorporation of growth elements into a previously verified system.
f. For functional paths not normally used (at periodic intervals).

Different verification methods are required for the three different system risk classifications as identified above in requirement d. Product assurance is required for all three classes. Verification and validation is required for classes two and three which include mission (payload) critical and support systems. Independent verification and validation is required for class one which includes crew/vehicle critical systems. See section 4.0 for definitions of the different verification methods.

After system risk assessment has been accomplished, performance/design requirements must be taken into account in determining verification requirements and for establishing verification procedures/methods. After verification methods are established, analysis/test objectives/conditions are established prior to development of the ground and on-orbit verification plan and implementation of the ground verification plan.

Evaluation of ground verification results with respect to requirements and resulting modifications of design or performance requirements shall precede implementation of on-orbit verification plans. Before verification requirements can be confirmed, additional modifications of design or performance requirements may be necessary. A Verification Completion Notice (VCN) system shall be employed to document final compliance with the verification requirements.

Full utilization shall be made of reflown elements whenever possible and/or practicable. Subsystems performance data from the preceding flight shall be provided to verify system performance and minimize ground checkout requirements for their next flight.

Orbital Replacement Units (ORU's) removed from a reflown element for field maintenance shall be reverified prior to reinstallation in the element. Functional verification of the affected paths within each ORU shall suffice when the repair involves replacement of plug-in assemblies only. Repair involving more than assembly replacement (e.g. soldering, potting) shall necessitate complete functional verification testing of the ORU including environmental acceptance testing when applicable.

Examples of typical areas requiring verification, along with several corresponding Verification Requirement Definition Sheets (VRDSs) are shown in Appendix B. A complete listing is contained in SS-HDBK-0002.

4.0 DEFINITIONS

Verification - A process wherein a determination is made that products conform to the design specifications and are free from manufacturing and workmanship defects. Areas to be considered during this process include performance, safety, reaction to design limits, fault tolerance, and error recovery. Encompassed within the verification process are analysis, testing, inspection, demonstration, or a combination thereof.

Analysis - A verification method utilizing analytical techniques and tools, such as math models, data compilation, similarity assessments, and validation of records, to confirm that requirements have been met.

Testing - A method of verification wherein performance requirements are measured during or after the controlled application of functional and environmental stimuli. These measurements may require the use of laboratory equipment such as thermal probes, furnace borescopes, and mini-gloveboxes, recorded data, procedures, test support items, or services.

Inspection - A method of verification of physical characteristics that determines compliance. Inspection uses visual methods, gauges, etc., to verify compliance with requirements of construction features, documents and drawings, workmanship, physical condition, and service code.

Demonstration - A method of verification denoting the qualitative determination of properties of an end item or component by observation of functional characteristics. Demonstration is used with or without special test equipment or instrumentation to verify requirement characteristics such as operational performance, human engineering features, service and access features, transportability, and displayed data.

On-Orbit Demonstrations - Performed to verify capability of SSF and SSFF systems during the following:

a. Initial buildup and assembly.
b. Final verification and demonstration of readiness to support operations.
d. Routine maintenance and repair.
4. Installation of update and growth items.

Product Assurance - A program for providing validation of the life cycle processes for SSF and SSFF systems and components. This validation assures that processes are approved and that appropriate controls are used within the life cycle. Process designs shall be evaluated to verify that appropriate subprocesses and controls are selected. The acceptance and operation of processes shall be monitored to assure that they are accomplished in accordance with approved procedures and that process components and systems comply with requirements.

Independent Verification and Validation (IV&V) - Processes that are accomplished through an organization independent of the development organization, to ensure that a complete and objective evaluation of the developer's products is accomplished. Organizational separation may be to a high level within an organization, contract, or company or by assigning the task to an organization, contract, or company other than the developer. The degree and extent of IV&V separation shall be a management decision made when system/component development or acquisition is initiated.

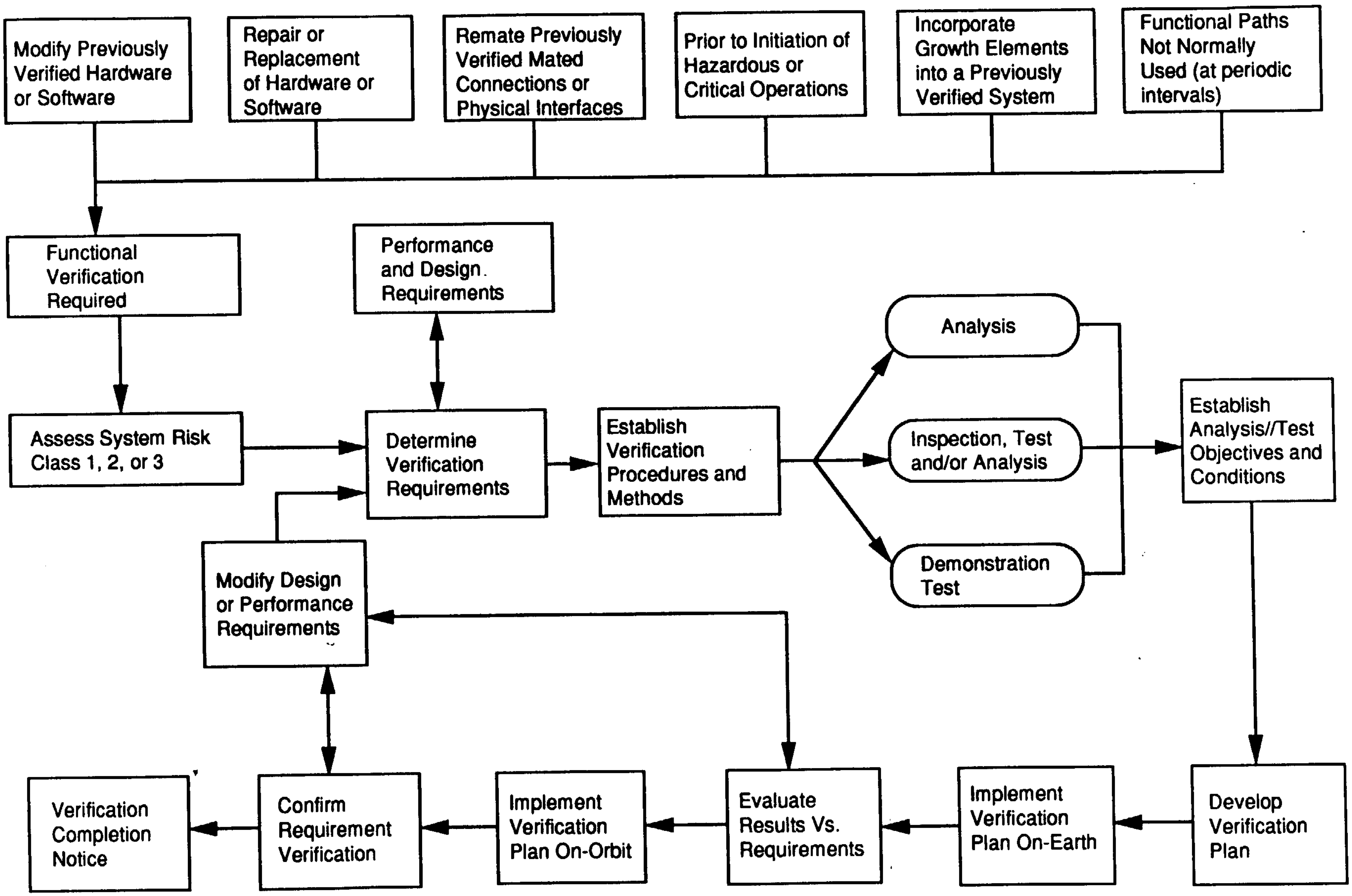
Validation - A process that determines that products comply with requirements and meet user needs. Validation ensures that each product reflects an accurate interpretation and execution of requirements and meets a level of functionality and performance that is acceptable to users.

5.0 REFERENCE DOCUMENTS

Document Number	Title
SSP 30467, Vol. 1 Revision C October 1991	Master Verification Requirements
SSP 30467, Vol. 2 Revision A January 15, 1989	Master Verification Implementation Requirements
SS-HDBK-0002 January 20, 1992 (Coordination Copy)	Integration Requirements on Payloads

APPENDIX A

VERIFICATION/REVERIFICATION PROCESS FLOW



VERIFICATION/REVERIFICATION PROCESS FLOW

APPENDIX B

VERIFICATION EXAMPLES

TABLE B3-1. SSF PAYLOAD VERIFICATION REQUIREMENTS
(Sheet 1 of 4)

REQUIREMENT IDENTIFICATION-NUMBER	REQUIREMENT TITLE	* METHOD OF VERIFICATION
	B3.1 <u>STRUCTURAL AND MECHANICAL</u>	
	B3.1.1 MASS	
B3.1.1.1	Weight	T
B3.1.1.2	Center of Gravity	A&T
	B3.1.2 MECHANICAL	
B3.1.2.1	Geometry	I
B3.1.2.2	Connection/Bolt Hole Location	I
B3.1.2.3	Attachment Hardware	I
B3.1.2.4	Surface Alignment and Finish	I
B3.1.2.5	Captive Parts	I
B3.1.2.6	Sharp Edges	I
B3.1.2.7	Equipment Adjustments	A
B3.1.2.8	Mechanical Stops	A&T
B3.1.2.9	Relatching	A&T
B3.1.2.10	Relief/Vent Valves Sizing	A&T
B3.1.2.11	Equipment Jettison	A&T
B3.1.2.12	Equipment Deployment	A or A&T
B3.1.2.13	Mechanical Energy	A&T
B3.1.2.14	Time-Sensitive Items	A
B3.1.2.15	Handling Clearances	A&T
B3.1.2.16	Non-Flight Equipment Removal	A&T
B3.1.2.17	Restraint of Stowage Equipment	A
B3.1.2.18	Containment of Materials	A or A&T
B3.1.2.19	Displays and Controls	I
B3.1.2.20	Passive Thermal Protection Interfaces	A or I
B3.1.2.21	Acoustic Levels	T
B3.1.2.22	Coolant Loop Cleanliness	T
B3.1.2.23	Coolant Loops Leakage	T
B3.1.2.24	Equipment Vacuum Vent Constraints	A or T
B3.1.2.25	Vacuum Vent Quick-Disconnect	A or T
B3.1.2.26	Vent Valve Functions	A&T
B3.1.2.27	Securing of Threaded Fasteners	I or T
B3.1.2.28	Pressure/Vacuum Line Identification	I

* T = TEST, A = ANALYSIS, I = INSPECTION

TABLE B3-1. SSF PAYLOAD VERIFICATION REQUIREMENTS
(Sheet 2 of 4)

REQUIREMENT IDENTIFICATION-NUMBER	REQUIREMENT TITLE	* METHOD OF VERIFICATION
	B3.1.3 STRUCTURES	
B3.1.3.1	Structural Safety Factors	A or A&T
B3.1.3.2	Lines and Fittings	A&T
B3.1.3.3	Pressure Tank, Actuating Cylinders, Valves, Filters, and Switches	A&T
B3.1.3.4	Natural Frequency	A or A&T
B3.1.3.5	Design Loading Life Spectrum	A&I
B3.1.3.6	Crew-Applied Loads	A or A&T
B3.1.3.7	Space Station Design Compatibility	A
B3.1.3.8	Pressurization/Depressurization	A or A&T
B3.1.3.9	Drawing Compliance for Safety-Critical Structures	I
	B3.1.4 MATERIALS	
B3.1.4.1	Toxic Offgassing	T
B3.1.4.2	Flammability, Nonmetallic Materials	A&I
B3.1.4.3	Stress Corrosion	A&I
B3.1.4.4	Forbidden Materials	A&I
B3.1.4.5	Contamination Sources	A
B3.1.4.6	Surface Cleanliness	A&I
B3.1.4.7	Cooling Fluid Compatibility	A
B3.1.4.8	Safety-Critical Structure Material Certification	I
B3.1.4.9	Thermal Vacuum Stability	A or A & T

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TABLE B3-1. SSF PAYLOAD VERIFICATION REQUIREMENTS
(Sheet 3 of 4)

REQUIREMENT IDENTIFICATION-NUMBER	REQUIREMENT TITLE	* METHOD OF VERIFICATION
	B3.2 ELECTRICAL	
	B3.2.1 ELECTRICAL POWER AND NETWORKS	
B3.2.1.1	Cable Continuity	T
B3.2.1.2	Isolation	T
B3.2.1.3	Secondary Return Grounding	T
B3.2.1.4	Incoming Signal and Return Lines Isolation	T
B3.2.1.5	Outgoing Signal Reference	A
B3.2.1.6	Twisted Multiconductor Shielding	I
B3.2.1.7	Shield Termination	I
B3.2.1.8	Coax Termination	I
B3.2.1.9	Case Electrical Bonding	A&I or T&I
B3.2.1.10	Cable Length	I
B3.2.1.11	Cable Types	I
B3.2.1.12	Connector Type/Wire Size	A&I
B3.2.1.13	Cable Interface Labeling	I
B3.2.1.14	Power Draw	A&T
B3.2.1.15	Overcurrent Protection	A
B3.2.1.16	Safety-Critical Circuits	A&T
B3.2.1.17	Caution and Warning Devices	T
	B3.2.2 ELECTROMAGNETIC COMPATIBILITY	
B3.2.2.1	Conducted EMI Emissions	T
B3.2.2.2	Radiated EMI Emissions	T
	B3.2.3 PYROTECHNIC CIRCUITS	
B3.2.3.	Pyrotechnic Initiators	A&I

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TABLE B3-1. SSF PAYLOAD VERIFICATION REQUIREMENTS
(Sheet 4 of 4)

REQUIREMENT IDENTIFICATION-NUMBER	REQUIREMENT TITLE	* METHOD OF VERIFICATION
	B3.3 DATA MANAGEMENT SUBSYTEMS/SOFTWARE	
B3,3,1	MDM Interface	A&T
B3.3.2	Experiment-to-Payload Bus Interfaces	A&T
B3.3.3	High Rate Data Link (HRDL) Interface	A&T
B3.3.4	Video System Interface	A&T
B3.3.5	Experiment Software Verification	A&T
B3.3.6	Time Distribution Bus (TDB) Interface	A&T
	B3.4 THERMAL/ECLS	
B3.4.1	Rack Equipment Pressure Drop	T
B3.4.2	Preintegrated Rack Pressure Drop	T
B3.4.3	Touch Temperature	A
B3.4.4	Allowable Heat Rejection	A&T
B3.4.5	Equipment Dewpoint (Flight)	A
B3.4.6	Loss of Cooling	A or A&T
B3.4.7	Equipment Dewpoint (Ground)	A
	B3.5 EXPERIMENT CHECKOUT EQUIPMENT (ECE)	
B3.5.1	ECE Circuit Protection	A&T
B3.5.2	GSE Structural Design	A&T
B3.5.3	ECE Fluid Systems Design	A&T
B3.5.4.	ECE/GSE Connector Interfaces	I
B3.5.5	GSE Fluid Line Marking	I
B3 5.6	GSE Electrical Return Line Isolation	A&T
B3.5.7	GSE Test Monitoring Cable	A&T

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Tracking Number	VERIFICATION REQUIREMENT DEFINITION SHEET	Payload Element
Requirement No. B3.1.2.6	Requirement Title SHARP EDGES	Method I

Verification Requirement:

Verify that sharp edges have been removed from equipment accessible to the crew.

Description of Requirement:

Sharp edges or protuberances that could injure flight or ground personnel during normal operations should be removed or shielded.

Data Required:

1. Stamped certificate of inspection for as-built hardware
2. Design drawings, parts list, waivers, and deviations as applicable
3. Drawings shall specify sharp edge and burr removal.

Applicable Documents and Notes:

NASA-STD-3000
SSP 30XXX, par. 220.7
NSTS 21000-IDD-MDK (Middeck Only)

Responsible Person: ______________________ **Org:** ________________
(Technical Resopnsibility)

Phone No: ____________________ **Data Submittal Date:** ________________

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Tracking Number	VERIFICATION REQUIREMENT DEFINITION SHEET	Payload Element
Requirement No. B3.1.2.9	Requirement Title RELATCHING	Method A and T

Verification Requirement:

Verify that equipment that requires relatching can be relatched under mission flight environments.

Description of Requirement:

The as-built relatching devices must conform to applicable drawings and specifications and must be capable of reliable activation in the flight environment. The unique characteristics of the low-g, vacuum, and thermal environments must be specifically addressed in the analysis. Redundant or backup systems must be verified to the same degree as primary systems. As a minimum, the latches must be tested in 1-g ambient environment.

Data Required:

1. Analysis Report
2. Certified Test Report
3. Drawings (installation/layout), waivers, and deviations as applicable

Applicable Documents and Notes:

ICD
MSFC-STD-1299
NSTS 21000-IDD-MDK (Middeck Only)

Responsible Person: ________________ **Org:** ____________
(Technical Resopnsibility)

Phone No: ______________ **Data Submittal Date:** ____________

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Tracking Number	VERIFICATION REQUIREMENT DEFINITION SHEET	Payload Element
Requirement No. B3.1.2.28	Requirement Title PRESSURE/VACUUM LINE IDENTIFICATION	Method I

Verification Requirement:

Verify the proper labeling/color coding and identification of pressure and vacuum lines.

Description of Requirement:

The labeling/color coding and identification of pressure and vacuum lines must agree with the as-built drawings and must conform to the specifications in MSFC-STD-530/1.

Data Required:

Certified inspection report

Applicable Documents and Notes:

MSFC-STD-530/1

Responsible Person: ____________________ **Org:** ____________________
(Technical Resopnsibility)

Phone No: ____________________ **Data Submittal Date:** ____________________

Tracking Number	VERIFICATION REQUIREMENT DEFINITION SHEET	Payload Element
Requirement No. B3.1.3.6	Requirement Title CREW-APPLIED LOADS	Method A or A and T

Verification Requirement:

Verify capability of equipment to withstand crew-applied loads.

Description of Requirement:

Determine by stress analysis, using appropriate factors of safety, the capability of all equipment that has a potential interface with the crew for operation, use, or impact (whether inadvertent or not) to withstand the crew-applied loads defined in the element Accommodation Handbooks, without surface penetration, failure of line/fittings, or failure of safety-critical structural items.

Data Required:

1. Design drawings, parts list, waivers, and deviations as applicable
2. Detailed stress analysis to include reference to discussion of assumptions/methology, description of computer models, margins of safety summary, and material properties summary
3. Safety-critical structures identification list with appropriate safety-critical structures analysis
4. Certified test report (If applicable)

Applicable Documents and Notes:

MSFC-HDBK-505
ICD
SSP 30XXX, par. 208
NSTS 21000-IDD-MDK (Middeck Only)

Responsible Person: ____________________ **Org:** ____________________
(Technical Resopnsibility)

Phone No: ____________________ **Data Submittal Date:** ____________________

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